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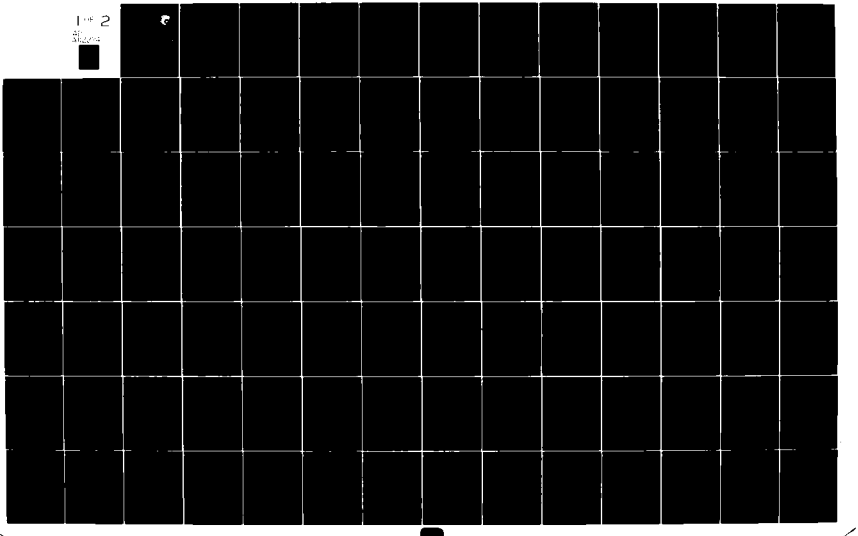

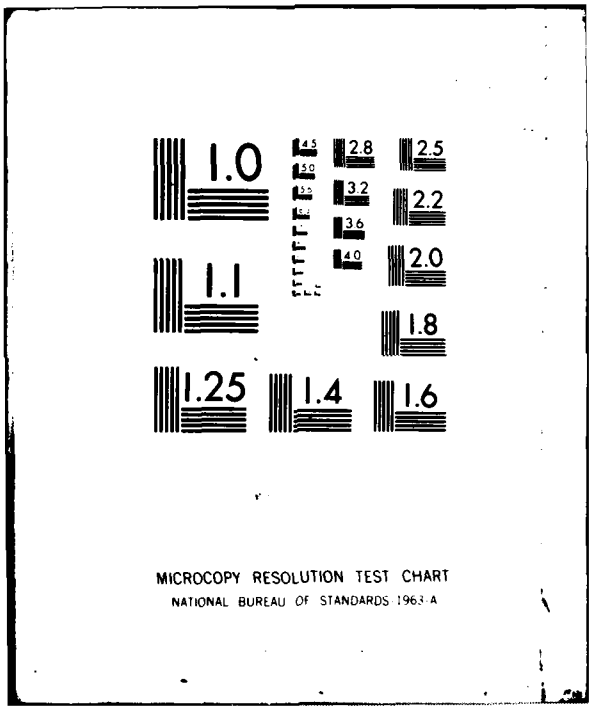
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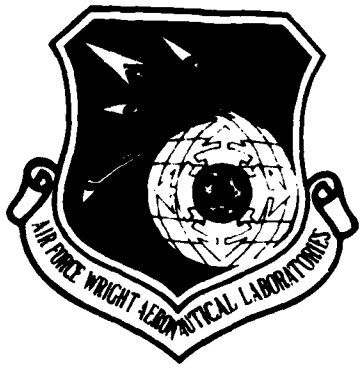

PANEL OPTIMIZATION WITH INTEGRATED SOFTWARE (POIS)
VOLUME II - USER INSTRUCTIONS--ECHO AND RRSYS

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Final Report for Period June 1976 - October 1980

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This technical report has been reviewed and is approved for publication.

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Optimization of structural panels with respect to bifurcation buckling constraints tends to lead to imperfection sensitive panels. The panels may not represent least weight configurations if the influence of always present geometrical imperfections are taken into account. A software package, POIS (Panel Optimization with Integrated Software) was developed in response to this problem. Here user instructions are presented for Computer Programs ECHO and RRSYS which are part of the POIS system. ECHO is a collection of computer programs for least weight design of stiffened structural panels subjected to

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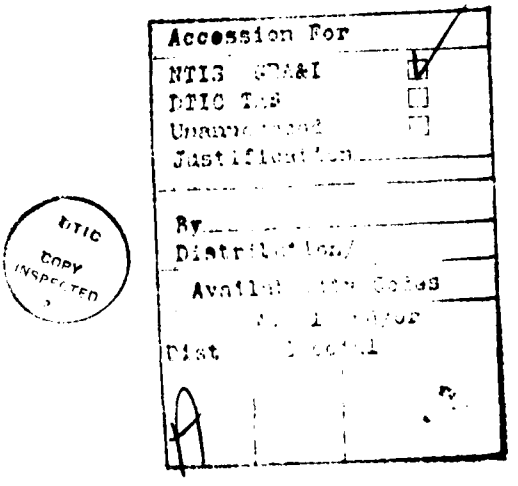
multiple combinations of inplane loads. ECHO includes program modules for optimization of perfect panels and nonlinear static stress analysis of panels with random imperfections. The optimization problem is carried out as a constrained function minimization problem in which buckling loads, stress, and strain may be constraints. RRSYS is a program system for the nonlinear analysis of elastic structures by means of the Rayleigh-Ritz method. RRSYS is designed to analyze such diverse structural phenomena as collapse, linear and nonlinear bifurcation, vibrations and transient dynamic response.

FOREWORD

This report was prepared by Lockheed Missiles and Space Company, Inc., Palo Alto Research Laboratories, 3251 Hanover Street, Palo Alto, California, in partial fulfillment of the requirements under Contract F33615-76-C-3105. The effort was initiated under Project 2307, "Research in Flight Vehicle Structures," Task 2307N102, "Research in the Behavior of Metallic and Composite Components of Air Frame Structures." The project monitor for the contract was Dr Narendra S. Khot of the Structures and Dynamics Division (AFWAL/FIBRA).

The technical work under the contract was performed during the period June 1976 through October 1980. Review report was submitted in October 1980 and the final report in March 1981.

The other reports published under this contract are "Imperfection Sensitivity of Optimized Structures," (AFWAL-TR-80-3128), "Numerical Procedure for Analysis of Structural Shells," (AFWAL-TR-80-3129), "Panel Optimization with Integrated Software (POIS)," (AFWAL-TR-80-3073, Vol I), "Design of Composite Material Structures for Buckling, An Evaluation of State-of-the-Art," (AFWAL-TR-81-3102), "Supplementary Study on the Sensitivity of Optimized Structures," (AFWAL-TR-81-3013).



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PART I, THE ECHO PROGRAM

SECTION 1

INTRODUCTION

ECHO is the code name for a collection of computer programs developed to implement portions of the strategy presented in Reference 1 for least weight design of stiffened structural panels subjected to multiple combinations of inplane loads. The strategy involves optimization of perfect panels with stresses (or strains) and bifurcation buckling loads as constraints, followed by nonlinear analyses of the optimized panels with random imperfections to determine failure loads based on collapse and maximum stress or strain criteria. After a design requirement has been defined (for example,a 99 percent probability that the critical load will exceed the design load) a statistical analysis yields optimum dimensions of panels including the effect of geometric imperfections. This strategy is depicted in Figure 1. The initial sizing, Phase 1, can be performed by PANDA (see Volume 1 of this report); Phase 2, the optimization of perfect panels, can be performed by ECHO; and Phase 3, the nonlinear analysis, can be performed by ECHO or RRSYS (see PART II).

ECHO includes program modules for optimization and for linear bifurcation buckling and nonlinear static stress analysis of elastic, stiffened, panels subjected to specified sets of inplane loads (Figure 2). The structural optimization problem involves minimization of an objective function subjected to nonlinear constraints. This optimization process requires two modules: a structural analyzer for evaluation of the objective function and constraint equations and an "optimizer" for minimization of the objective function consistent with the constraints. The numerical procedure used to compute the minimum is sometimes called "parameter optimization" or "nonlinear programming"(NLP).

The structure under consideration is a flat or cylindrical panel stiffened by rings and stringers. Stiffener cross-sections are modeled as assemblages of flat segments which can be made into stiffener types such as a blade, T, J, hat, corrugation, etc. Panel and stiffener walls are multiple layers of orthotropic materials. A layer (lamina) is defined by a thickness, material orientation angle (winding angle) and material type. Arbitrary boundary conditions may be specified on each of the four edges of the panel, including simple support (antisymmetry), fixed, free, and symmetry.

In a least-weight design problem (or bifurcation buckling analysis) the design loads are sets of combined inplane loads which result in uniform membrane strains in the panel and stiffeners and a uniform shear strain in the panel. Loading in a nonlinear analysis is applied through gradual incrementation of the combined membrane strains. The inplane loading can be combined with small random out-of-plane forces which simulate imperfections.

This approach leads to a much less expensive analysis than would be the case if actual geometric imperfections were defined.

In the structural optimization problem solved here the objective function is the total stiffened panel weight. Design variables (parameters) include stiffener segment widths, layer thicknesses, and material orientation angles. For a particular design problem any subset of the design variables is allowed to vary independently of the other variables. Variables in this subset are called "decision", "master", "sizing", or "independent" variables. The other design parameters may be held fixed or be linked to the decision and fixed variables by means of a set of linear equations. Constraints are represented by inequality equations of the design variables which must be satisfied for a feasible design. These include constraints on local and general bifurcation buckling eigenvalues, constraints on maximum stress or strain, and side constraints which are the upper and lower bounds on the decision variables.

The ECHO program system was developed with the following important guidelines:

1. control of operations to be provided by the user,
2. use of existing structural and optimizer modules,
3. ease of modification and extension,
4. efficency with respect to computer time.

Operations performed by programs ECHO and OEXEC of the ECHO system are shown in Figure 3. Program ECHO provides user options to print information about ECHO, read input data, execute program OEXEC, and catalog files. Program OEXEC controls all operations related to a structural or optimization analysis. The structural analyzers are indirectly coupled with OEXEC. Thus, they are executed by control statements in a "procedure file" generated in OEXEC. Input to an analyzer is computed and written on a file. After execution, output from the analyzer is written on another file which can be read in OEXEC. All other operations, such as evaluation of the objective function and constraints and execution of the optimizer, are performed by subroutines in OEXEC. A file containing input data required by RRSYS for a nonlinear analysis can also be generated.

At present, the following programs are included in the ECHO collection:

STAGSC-1 (Structural Analysis of General Shells),
SFRITZ (STAGS Functional Rayleigh-Ritz),
FRITZ (Functional Rayleigh-Ritz),
VIPASA (Vibration and Instability of Plate Assemblies Including Shear and Anisotropy)
PASCO (Panel Analysis and Sizing Code)
CONMIN (Constrained Function Minimization)

Note that VIPASA and CONMIN are in subroutine form in program PASCO. An optimizer called ALMIN (Adaptive Lagrange Minimization) with the potential of greater efficiency than CONMIM has been developed under the present contract. As reported in Refer-

ence 2 the new algorithm has been made operational; however, it has not been exercised enough to be suitable for production applications.

The organization of ECHO allows other structural analyzers and optimizers to be included without major modifications of the system.

A short description of the analysis programs presently contained in the ECHO system follows:

STAGSC-1

STAGSC-1 is the most recent version of the STAGS series of computer programs. STAGS provides options for linear and nonlinear static stress, stability, vibration, and transient analysis of general shells. The program is based on the finite element method and is described in some detail in Reference 3. User instructions are given in Reference 4. STAGS consists of two processors STAGS1 and STAGS2. STAGS1 is a preprocessor which reads the input and generates some intermediate results needed for the structural analysis in STAGS2. In ECHO, the linear bifurcation buckling option with uniform prestress is used to obtain eigenvalues to represent the buckling constraints. The use of STAGS in ECHO provides generality with respect to the geometry, loads,and boundary conditions of the structural configuration to be optimized. However, in optimization, with the eigenvalue analysis repeated a large number of times, the straightforward finite element analysis in STAGS often leads to excessive computer time. Greater computational efficiency can be achieved by use of the programs SFRITZ and FRITZ.

SFRITZ

SFRITZ is a program for linear bifurcation buckling analysis of structures which can be defined in STAGS. SFRITZ is based on a combination of Rayleigh-Ritz techniques and finite element discretization. Trigonometric basis functions selected by the user determine displacement and rotation values at nodes of the finite element model providing a set of basis vectors. The buckling pattern is represented as a linear combination of these basis vectors. The finite element discretization is then used to define the buckling problem in a reduced system with the amplitudes of the user-selected basis functions as the generalized degrees of freedom.

FRITZ

FRITZ provides linear bifurcation buckling and nonlinear collapse analysis of flat or cylindrical rectangular panels by use of Rayleigh-Ritz functional methods. As with SFRITZ, the user selects trigonometric functions as the basis functions for the analysis. A discrete grid is also defined for the panel as in a STAGS model. However, energy integration in FRITZ proceeds by direct numerical computation using the trigonometric functions directly

rather than by use of a finite element model. In general, the direct Rayleigh-Ritz analysis used in FRITZ achieves much greater economy than a corresponding finite element analysis and is thus particularly suited for the study of imperfection sensitivity of panels. The choice of trigonometric functions to be included in the basis vector space is controlled by the user. The user has options to define normal as well as inplane displacement functions, or to define normal displacements only. In the latter case, corresponding inplane displacements are computed from the inplane equilibrium equations. While SFRITZ can be applied to very general structures, FRITZ can at present only be used for analysis of flat or curved panels. The use of numerical integration, however, permits the treatment of various boundary conditions and loadings.

In the interest of economy, an additional user option has been introduced: The geometric imperfections can be simulated through the application of random normal forces to the panel. In a nonlinear analysis with user-defined displacement functions the major part of the computer time is spent on the computation of the coefficients in the reduced global vector space. Since these are functions of the initial geometric imperfections they must be recomputed each time the reduced system is integrated. Therefore, the analysis becomes much less expensive if the imperfections are simulated by use of normal forces. The program user defines what can be regarded as a quality parameter. FRITZ then defines the normal loading in the form of a Fourier series with random coefficients.

Each coefficient in this series is then independently determined as the product of the quality parameter and a random number with uniform probability in the range -1 to + 1. During integration of the reduced system the normal loads are held constant while the inplane loading is gradually increased.

PASCO-VIPASA/CONMIN

The computer program PASCO has options for bifurcation buckling and vibration analyses, and optimization of prismatic structures. Structural analyses are performed with program VIPASA and optimization is performed by program CONMIN. In an optimization problem, behavioral constraints considered include bifurcation buckling, material strength, stiffness, and vibration frequency. A description of PASCO is given in Reference 5 and user instructions are given in Reference 6. VIPASA will handle an arbitrary assemblage of thin, flat, rectangular plate elements linked together along edges parallel to the axial direction (X). The wall construction is of laminated orthotropic materials which must be symmetric about the midsurface of an element. Edges in the transverse direction are simply supported and edges in the X direction may have arbitrary support conditions. Loading may be by inplane stress resultants, a bending moment in the transverse direction (Mx), and thermal gradients uniform in the X direction. Buckling patterns are therefore sinusoidal in the axial direction. Solutions of the differential equations for buckling of

plates are obtained and undetermined coefficients are computed from the compatibility conditions between adjacent plate elements. Rings (transverse stiffeners) cannot be included. Shear buckling is obtained in an approximate manner. VIPASA does not distinguish between local and general instability modes, but calculates mode shapes rigorously, as would a finite element program. Thus, modes which consist of general instability with local perturbations due to stringers are calculated in VIPASA. The formulation of VIPASA is given in Reference 7.

In ECHO, program PASCO, which contains VIPASA and CONMIN in subroutine form, can be used directly for structural and optimization analyses of flat panels stiffened by stringers.

CONMIN

CONMIN is a computer program for solving the NLP problem. A description of the method on which CONMIN is based is given in Reference 8 and user instructions are given in Reference 9. The NLP algorithm is based on Zoutendijk's method of feasible directions (Reference 10). Vanderplaats modified the algorithm to improve efficiency, numerical stability and to deal with infeasible designs. The general problem treated by CONMIN is to minimize a function of several parameters subjected to nonlinear inequality constraints and side constraints (upper and lower bounds) on the parameters.

The technique involves minimizing the objective function until one or more of the constraints become active. The process proceeds iteratively by following the constraint boundaries in a direction such that the objective function continues to decrease. When a point is reached such that no further decrease in the the function can be obtained, the process is terminated. Infeasible designs (one or more constraints are violated) can be used as starting values. In this case the algorithm permits an increase in the objective function provided this leads to the elimination of constraint violation.

The program requires the user to supply values and gradients for the objective function and constraints. If analytical gradients are not availiable, they can be computed by finite difference approximations in CONMIN.

Programs ECHO and OEXEC implement the least weight design problem formulated in SECTION 2. Information about the program capabilities, organization, and operation is presented in SECTION 3. Examples are given in SECTION 4. All of the input data requirements are presented in APPENDICES A and B. Procedure files are in APPENDIX C to aid the user in executing programs in the ECHO system. Theory for the FRITZ program is presented in APPENDIX D.

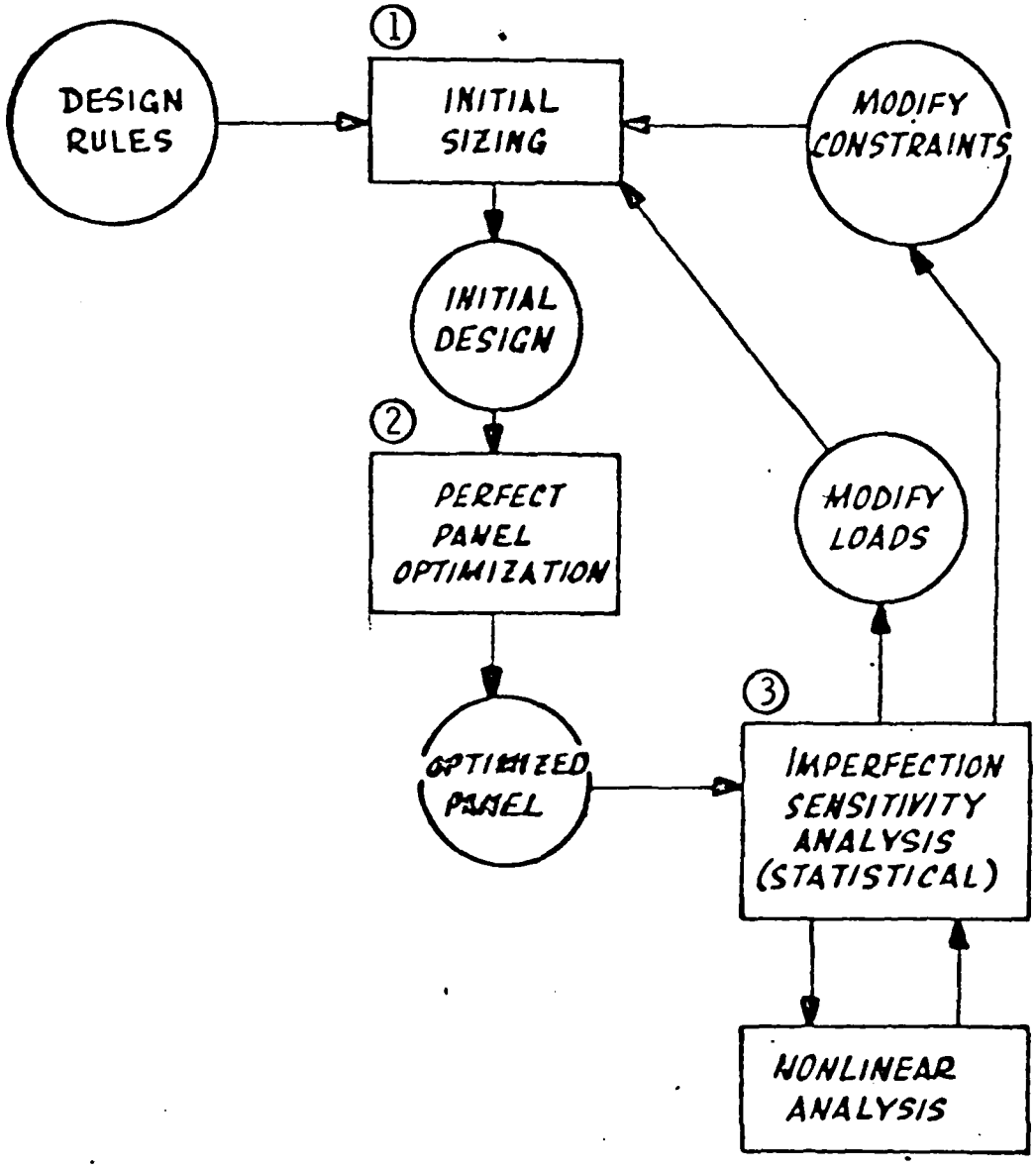


Figure 1 Optimization Procedure in the Presence of Random Imperfections

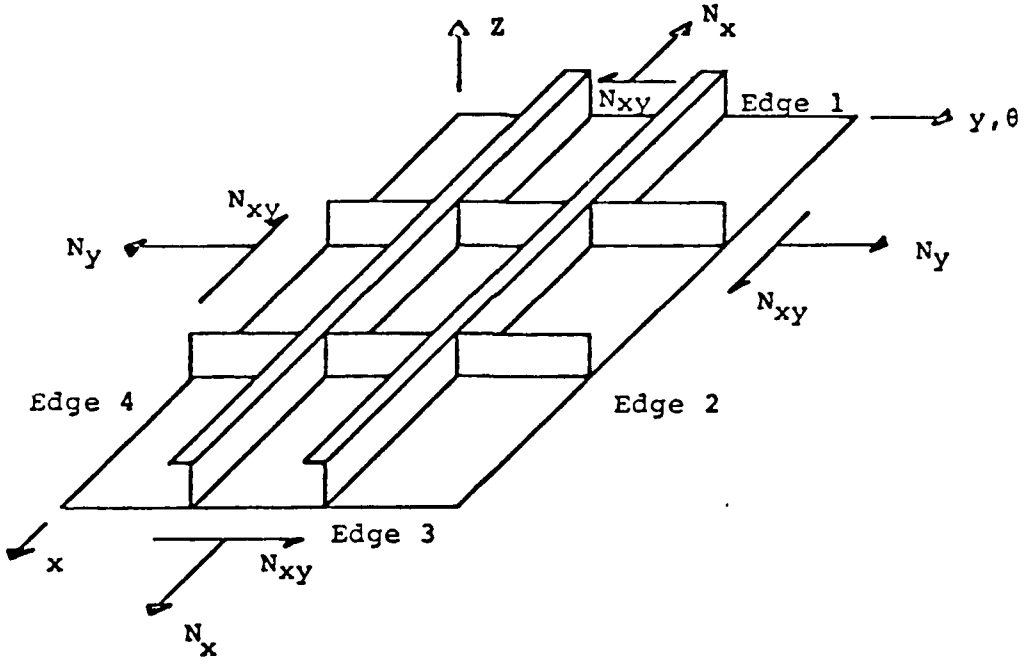


Figure 2 Stiffened Panel and Positive Load System

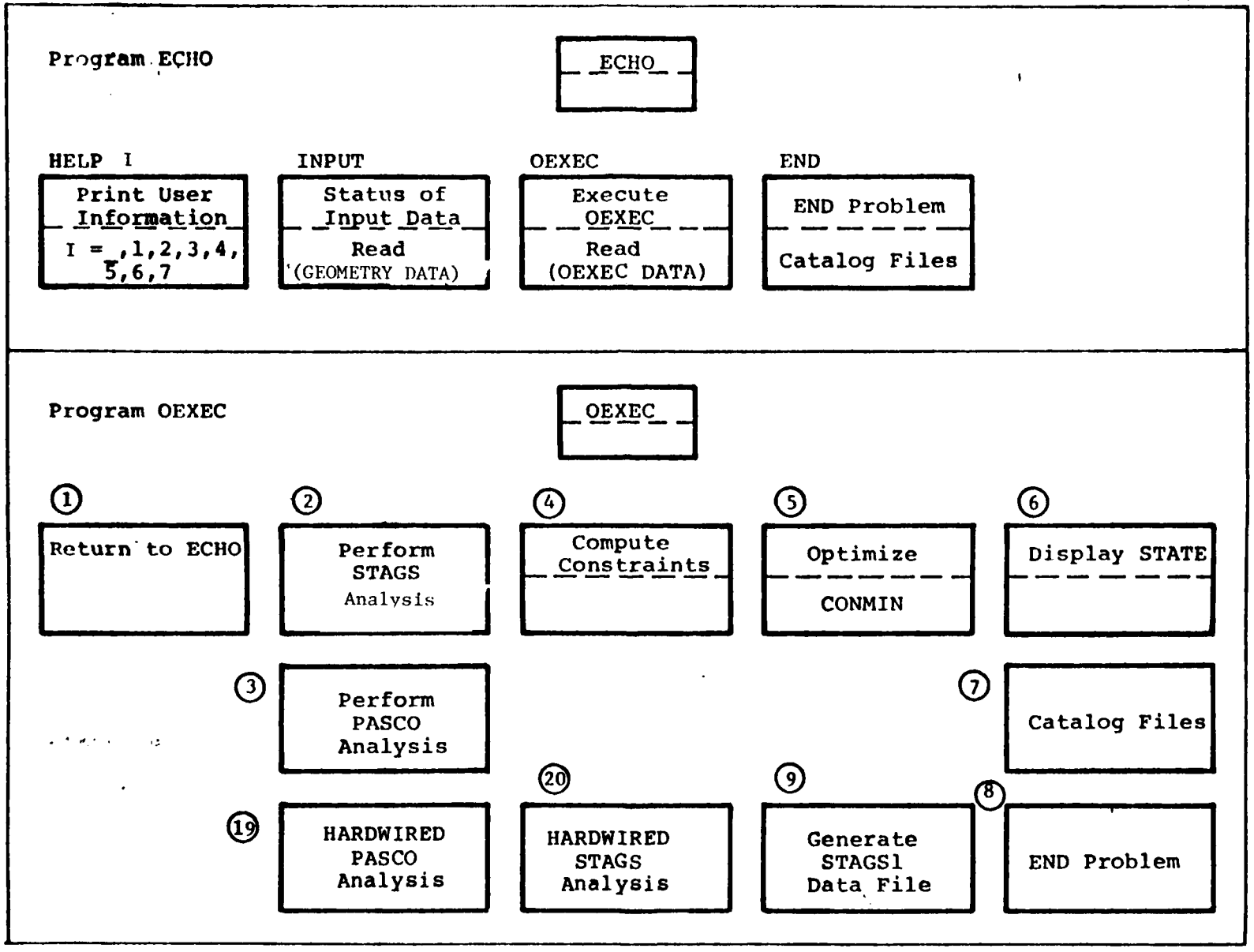


Figure 3 Structure of Programs ECHO AND OEXEC

SECTION 2

LEAST WEIGHT DESIGN PROBLEM

2.1 General

A method is presented for the least weight design of stiffened panels. For given sets of inplane loads the design requirements are that bifurcation buckling loads will not be less than the design loads, that stresses or strains will not exceed certain values defined by material allowables in a design (failure) criterion, and that dimensions will remain within prescribed values. The design problem is formulated such that existing NLP algorithms can be utilized to perform the constrained function minimization problem.

2.2 Structure and Design Variables

The structure to be optimized is an elastic, stiffened, perfect panel of specified material, boundary conditions, and sets of uniform inplane loads. The panel can be flat or cylindrical and stiffened by equally spaced stringers and rings. Stiffener cross-sections are built up of flat segments each of which can be rotated by a given angle and joined together in a prescribed manner. This scheme allows the user to generate blade, T, J, hat and other types of sections. Panel and stiffener segment walls are multiple layers of orthotropic materials. Each layer has a given thickness (T), material, and angle (ZET) which relates the material orientation (1-direction) relative to the panel (X- direction) or stiffener segment axis (X-direction for stringer, Y-direction for ring). Boundary conditions which can be prescribed along the panel edges are simple support (antimetric), fixed, free, and symmetry.

Design variables include stiffener segment widths (WS(I)), layer thicknesses (T(I)), and material orientation angles (ZET(I)). The array DV of all design variables is

```
DV=((WS(J),J=1,NSW),(T(J),J=1,NDT),(ZET(J),J=1,NDT))     (1)
DV=(DV(1),DV(2),----------DV(M))
```

in which NSW is the number of distinct stiffener widths, NDT is the number of distinct layers and M is the total number (NSW + 2*NDT) of possible design variables. Each variable DV(I) can be classified into one of the following three groups:

1. Fixed (inert) variable-
   DV(I) remains fixed throughout the optimization process.
2. Decision (master, sizing, independent) variable -
   DV(I) varies throughout the optimization process.
3. Linked (slave, dependent) variable -
   DV(I) is expressed as a linear combination of other variables.

This classification is accomplished in ECHO by assigning each

element of the vector IVN [IVN(I),I=1,2,...M] the value 0, 1, or 2 depending on the group to which the corresponding design variable DV(I) belongs. For example, the array

IVN=(1,1,1,1,2,0,0,2)

signifies that DV(1),--DV(4) are decision variables; DV(5) and DV(8) are linked variables and DV(6) and DV(7) are fixed variables. When variables are linked, a number of linear equations equal to the number (NLE) of linked variables relating the variables must be specified. For example

$$A(I,J)*DV(J)=C(I) \qquad I=1,2\text{--NLE};J=1,2\text{--M} \qquad (2)$$

in which A is a matrix of user-provided coefficients and C is a user-provided vector. The subset of of DV which are decision variables is denoted by the array X. The number (NDV) of decision variables is equal to the sum of all IVN(I) which have values of 1.

The inplane load condition,

$$Q(J)=(NX(J),NY(J),NXY(J)) \qquad J=1,2,---NLOAD \qquad (3)$$

in which Q(J) is the Jth design load set and NLOAD is the number of sets, is assumed to result in uniform membrane strain fields (EPKL(J),J=1,NLOAD). Then the Jth stress field (SKL(J)) in a particular layer (I) is expressed as

$$SKL(J)=C*EPKL(J) \qquad K,L=X,Y \text{ or } 1,2 \qquad (4)$$

in which the matrix C defines the appropriate constitutive relation for the material, orientation, and definition of EPKL(J). Thus given strains in the panel X,Y directions, stresses in the material directions 1,2 can be computed if the original constiutive matrix is transformed.

2.3 Constrained Function Minimization Problem

The objective is to find a combination of the decision variables XF(I) which make the total structural weight a minimum and do not cause a violation of constraints on buckling loads, material allowables and dimensional bounds on the variables X(I). This problem can be stated as follows: Find the set XF(I) of the variables X(I) such that

$$F[XF(I)]=MIN\{F[X(I)]\} \qquad I=1,2,---NDV \qquad (5)$$

subject to inequality constraints

$$G(J) \leq 0 \qquad J=1,2,---NCON \qquad (6)$$

and side constraints

$$XLB(I) \leq X(I) \leq XUB(I) \qquad I=1,2,---NDV \qquad (7)$$

in which the objective function F[X(I)] is the weight and XUB, XLB are upper and lower bounds on the decision variables X(I).

Constraints on the buckling load can be written as

$$G(K)=P(N) - EIG(N,J) \leq 0 \qquad \begin{matrix} N=1,2,--NM \quad J=1,2,--NLOAD \\ K=1,2,--NBC \quad (NBC=NM*NLOAD) \end{matrix} \qquad (8)$$

in which EIG(N,J) is the lowest bifurcation buckling eigenvalue associated with load case J and the the Nth buckling mode index, and P(N) is a mode separation parameter (PHI). Here PHI is the ratio between local and general buckling loads. In general buckling the buckle pattern (eigenvector) is such that the stiffeners deform normal to the plane of the panel. For local buckling the panel buckles between stiffeners (stiffeners are nodal lines in the buckle pattern). Also buckling of the stiffeners constiutes local buckling when the stiffener attachment line is a nodal line. The concept then is to generate buckling constraints based on general and local buckling and to have local buckling a factor PHI less than general buckling load. In a STAGS (FRITZ or SFRITZ) analysis modelings of the structure are constructed such that the minimum eigenvalue of the model represents general or local buckling. For example, a modeling of the structure in STAGS with smeared stiffeners will have a buckling solution which corresponds to general instability while a modeling of the structure between stiffeners will have a buckling solution which corresponds to local instability. With FRITZ and SFRITZ buckling modes are supplied by the user; therefore, a modeling of the structure with discrete stiffeners can correspond to general or local buckling depending on the choice of modal functions. With PHI less than one at least two models must be used to generate constraints for general and local buckling.

Maximum stress and maximum strain criteria are included. Maximum allowable stresses or strains are given for tension, compression and shear in the principal material directions 1 and 2. Constraint equations for these conditions can be written as

$$G(K)= S(J)/SA(J) - 1. \leq 0 \qquad K=NBC+1,---NCON \qquad (9)$$

in which S(J) is a stress or strain component and SA(J) is the corresponding allowable value for load case J.

2.3.1 Optimization subsynthesis

Buckling and material allowable constraints are complex implicit functions of the design variables. Thus the problem is made tractable,as proposed by Schmit (Reference 11), by a sequence of approximate explicit problems which retain the features of the original problem. This involves generating first order Taylor series expansions in terms of the decision variables X(I) for each of the behavioral constraint functions G(K), as

$$G(K)=GS(K) + SUM[(X(I)-XS(I))*DG(K,I)],I=1,NDV \quad (10)$$

in which XS(I) are values of X(I) at the point of expansion (the starting values of each subsynthesis cycle), GS(K) is the value of G(K) evaluated with the starting values, and DG(K,I) is the derivative of G(K) with respect to the variable X(I). DG(K,I) is computed by the forward difference expression

$$DG(K,I)=(G1(K) - GS(K))/ (DELDV*XS(I)) \quad (11)$$
$$X1(I)= (1 + DELDV)* XS(I)$$
$$X1(K)= XS(K) \qquad \text{FOR K NOT EQUAL TO I}$$

where G1(K) is the value of G(K) evaluated with the values X1(I). The parameter DELDV must be chosen to reflect the range over which the expansion is valid. The upper and lower bounds of X(I) must be restricted for each subsynthesis cycle to retain the non-linear behavior of the constraints. As suggested by Schmit the upper and lower bounds (move limits) for each cycle (N) are given by

$$XUM(I)=(1 + DX)*XS(I) \quad (12)$$
$$XLM(I)=(1 - DX)*XS(I)$$
$$DX=SMOVE*SFACT**(N-1)$$

where SMOVE and SFACT are input scalars.

A particular subsynthesis cycle involves generating a sufficient number of eigenvalues and strain fields to compute the expansions given in Equation 10, and performing a constrained minimization problem with new constraints, new side constraints and starting values obtained from the previous cycle. Overall convergence is assumed to be satisfied when

$$\{SUM[(ABS(X(I)/XS(I) -1.)/NDV],I=1,NDV\} < DDV \quad (13)$$

in which DDV is some specified small value less than the value of DX in Equation 12. In a given problem the number of cycles required depends on starting values, move limits, and the convergence value DDV.

SECTION 3

USER INFORMATION

ECHO is described in this section with respect to capabilities, organization, and operation. Required input data are presented in Appendices A and B.

3.1 Capabilities

ECHO is designed to perform least weight design, linear bifurcation buckling analysis, and nonlinear static stress analysis of elastic, stiffened panels. ECHO includes computer software that performs the following functions:

1. Transforms output data from the initial sizing program PANDA to data which can be used by ECHO.
2. Optimizes perfect panels with data from program PANDA or other sources. Results of the optimization can be stored in a file.
3. Performs bifurcation buckling or nonlinear static stress analysis with data from either of the two preceeding operations.
4. Generates STAGS1 type data file for nonlinear analysis in RRSYS.

3.2 Organization

Computer software at present consists of programs ECHO, OEXEC, STAGS1, STAGS2, SFRITZ, FRITZ, PASCO, EIGENS, STORE, and COMMON; and files ECHOI and ECHOP. The programs perform one or more of the following functions: structural analysis, NLP problem, utility, or controls operations. File ECHOI contains user information and file ECHOP contains procedure files (see Appendix C) for sets of standard runstreams. Program STORE (see Appendix B) is used to transform PANDA data to ECHO data.

The structure of programs ECHO and OEXEC is shown in Figure 3. Program ECHO controls printing of user information from file ECHOI; input of data (GEOMETRY DATA) which defines the problem geometry, loading, material, boundary conditions, and optimization parameters; execution of program OEXEC and data input (OEXEC DATA); and cataloging files. Data required to perform the above operations are called (ECHO DATA).

Progran OEXEC controls all operations related to a structural or optimization analysis through user supplied data called (OEXEC DATA). If the hardwired options are used no user data are required by OEXEC. The structural analyzers (STAGS, SFRITZ, FRITZ and PASCO) are indirectly coupled with OEXEC in that they are executed by control statements placed in the "run stream" through a "procedure file" generated in OEXEC. Required data for these programs are computed and stored in a file called (DAT). After execution the necessary data are written to another file. For

example, eigenvalues computed by FRITZ are in a file called (EIG). All operations for an optimization problem such as evaluation of the objective function and constraints are directly coupled. Thus the optimizer CONMIN resides as a set of subroutines in OEXEC.

3.3 Operation

A number of procedures are included on file ECHOP to aid the user in the execution of programs in the ECHO system. The procedures and typical runstreams (control statements) are given in Appendix C. The following discussion presents techniques for performing the operations in Section 3.1 utilizing procedure files.

3.3.1 Initial sizing data

Assume that program PANDA (Volume I) has been executed to obtain initial sizing data for a panel subjected to various load factors and various mode separation parameters (PHI). Results of each case have been written on a file and the file has been cataloged with the name PAM. The user now wants to use these results to perform certain analyses with ECHO. To accomplish this task program STORE must be executed with STORE data (Appendix B) and the resulting ECHO (GEOMETRY FILE) cataloged with the name of ISCAS1 for further use. Procedure file ECHOPE can be used for this task. Following is the runstream in which the data for STORE is on cards:

```
(JOB CARD)
ATTACH(P,PAN)
COPYBF(INPUT,DAT)
BEGIN,ECHOPE,ECHOP.
CATALOG(E,ISCAS1)
(EOR)
(STORE DATA)
(EOF)
```

File ISCAS1 contains a number of initial sizing cases in (GEOMETRY FILE) form.

Now assume that certain of the parameters must be changed; such as, problem type, optimization parameters, etc. The problem is to update the (GEOMETRY FILE) with (GEOMETRY DATA). Note that the (GEOMETRY DATA) need contain only data sets which change. Procedure file ECHOFU can be used for this operation. Let the (GEOMETRY DATA) be on cards and the updated (GEOMETRY FILE) be cataloged under the name ESCAS1. Following is the runstream for this task:

```
(JOB CARD)
ATTACH(E,ISCAS1)
COPYBF(INPUT,DATG)
BEGIN,ECHOFU,ECHOP.
CATALOG(EE,ESCAS1)
```

```
(EOR)
(GEOMETRY DATA)
(EOF)
```

The preceeding two runs can be combined so that only one file need be cataloged by the following runstream:

```
(JOB CARD)
ATTACH(P,PAN)
COPYBR(INPUT,DAT)
COPYBF(INPUT,DATG)
BEGIN,ECHOPE,ECHOP.
BEGIN,ECHOFU,ECHOP.
CATALOG(EE,ESCAS1)
(EOR)
(STORE DATA)
(EOR)
(GEOMETRY DATA)
(EOF)
```

3.3.2 Optimization and structural analysis

Assume now that initial sizing data have been obtained as presented in Section 3.3.2. The task is to optimize the panels using one of the structural analyzers and optimizers in the ECHO system and to catalog the updated (GEOMETRY FILE) type data. Procedure file ECHOGF can be used for this task. The user has the option to update the (GEOMETRY FILE) with (GEOMETRY DATA) which for this example is on cards. Following is the runstream in which the optimized panel data are cataloged with the name EFCAS1.

```
(JOB CARD)
ATTACH(PD,ESCAS1)
COPYBF(INPUT,DATG)
BEGIN,ECHOGF,ECHOP.
CATALOG(EC,EFCAS1)
(EOR)
(GEOMETRY DATA)
(EOF)
```

The optimized panels are now defined by data on file EFCAS1.

To perform bifurcation buckling or nonlinear static stress analyses on each of the panels the user can use the same procedure file (ECHOGF); however, the (GEOMETRY DATA) must change to reflect the analysis type. Note that the updated (GEOMETRY FILE) may not have to be cataloged since the geometry has not changed. The runstream for this case is as follows:

```
(JOB CARD)
ATTACH(PD,EFCAS1)
```

```
COPYBF(INPUT,DATG)
BEGIN,ECHOGF,ECHOP.
(EOR)
(GEOMETRY DATA)
(EOF)
```

Procedure files ECHOFG and ECHOGO can be used when initial sizing data are not available. ECHOFG is used for optimization or analysis problems in which the only input is (GEOMETRY DATA). ECHOGO is used only for an optimization problem in which the objective is to optimize with various load factors and values of PHI from an initial starting geometry, load set, and value of PHI. For more details see Appendix C.

3.3.3 Data file for RRSYS

Now that a perfect panel has been optimized as given in Section 3.3.2 and the (GEOMETRY FILE) type data are on file EFCAS1, the user wants to perform nonlinear analyses utilizing RRSYS. The task here is to generate STAGS1 type data for each case defined on file EFCAS1 and to catalog the data. Procedure file ECHOSD is designed for this purpose. A sample runstream is as follows:

```
(JOB CARD)
ATTACH(E,EFCAS1)
COPYBF(INPUT,DATG)
BEGIN,ECHOSD,ECHOP.
CATALOG(SDA,SDCAS1)
(EOR)
(GEOMETRY DATA)
(EOF)
```

in which (GEOMETRY DATA) is on cards and reflects necesary changes. File SDCAS1 contains data files for each case defined on file EFCAS1.

SECTION 4

EXAMPLES

4.1 General

Examples are presented to familiarize the user with features of the ECHO system, input data requirements, and ECHO output. Figure 4 defines the geometry of four structural configurations used as examples. Example 1 is an unstiffened square plate simply supported along all edges and subjected to a load system consisting of four load sets. Example 2 is a blade stiffened square plate simply supported along all edges and subjected to axial compression. Example 3 is a blade stiffened wide plate simply supported on the loaded edges and subjected to axial compression. Example 4 is an unstiffened cylindrical panel simply supported along all edges and subjected to axial compression. Walls of the panels are either a single layer isotropic material or multiple layers of an orthotropic material (composite). Both wall constructions are used in Example 1, Examples 2 and 3 are isotropic, and Example 4 is a composite.

At this point the user may wish to scan APPENDIX A to become acquainted with the three types of input data sets i.e. (ECHO DATA), (OEXEC DATA), and (GEOMETRY DATA). In the examples no (OEXEC DATA) is required since the hardwired option is used.

For the novice user an example problem is included in procedure file ECHOP (see APPENDIX C) to run Example 3 with the following card input runstream:

```
(JOB CARD)
BEGIN,ECHOEX,ECHOP.
(EOF)
```

On the (JOB CARD) the user should include the following CDC parameters: CM100000, T250, IO500. The control card executes procedure ECHOEX which is on file ECHOP. The (EOF) represents and end-of-file mark which is a multiple punch 6 7 8 9 in column 1 on a card.

Next (GEOMETRY DATA) and (ECHO DATA) are described with respect to the example problems. Then each example is discussed in terms of input and output.

4.1.1 (GEOMETRY DATA) Description

(GEOMETRY DATA) defines the structure, loading, boundary conditions, analysis type, and optimization parameters. As seen in APPENDIX A.4, there are fifteen (15) possible subsets of data each of which is preceeded by a label. Subsets which are always required are: PANEL, MATERIAL, LOAD, BOUNDARY, THICKNESS, WALL, CONTROL, and END. If stiffeners are present the subset STIFFENER is required. For an optimization problem CONSTRAINT, DECISION, and OPTIMIZE must be included. Then if the structural analyzer

FRITZ, SFRITZ, or STAGS is used the subset STAGS is required. The remaining two subsets TITLE and SAVE are optional.

PANEL

Four parameters KMT, KPT, NST, NRG and three dimensions XL, XT, RA are required as input under this label. The following table gives the proper data for each example.

Example NUMBER	KMT	KPT	NST	NRG	XL	XT	RA
1	1	1	0	0	10.0	10.0	0.0
2	1	1	1	0	10.0	10.0	0.0
3	2	1	0	0	10.0	7.5	0.0
4	1	2	0	0	30.0	17.19	80.0

For Example 1, an unstiffened plate, KMT=1 implies that the edges of the panel are unstiffened, KPT=1 identifies the panel as being flat, and NST=NRG=0 denotes that the number of stringers and rings between the panel edges is zero. Dimensions XL and XT are the length and width of the panel in inches. Although not needed for a flat plate the radius (RA) must be given a value for CDC free field type input. In Example 4, XT is the angle in degrees which defines the arc length (LY) of a cylindrical panel by the expression

$$LY = 0.1745329*RA*XT .$$

MATERIAL

In ECHO, the structure can be composed of ten orthotropic materials defined by three modulii (E11, E22, E33), a Poisson's ratio (ANU1), density (RHO), and two coefficients of thermal expansion (TA1, TA2). For an isotropic material E11 must be defined; however, E22 and E33 can be set to zero in which case these values are computed internally. The thermal expansion terms are not used in the present version of ECHO but must be included in the input. The following table gives the material propetry data used in the examples.

Example Number	E11 psi 10+6	E22 psi 10+6	E33 psi 10+6	ANU1	RHO lb/in	TA1	TA2
1,2,3	10.0	0.	0.	0.3	0.10	0.	0.
1,4	23.0	1.7	0.94	0.304	0.054	0.	0.

LOAD

In a bifurcation buckling or optimization problem the structure can be loaded by at most four sets of stress resultants NXX, NYY, NXY. The positive sense of these loads is shown in Figure 2. The load systems used in the examples are given in the following table.

Example Number	NXX lb/in	NYY lb/in	NXY lb/in
1	-1000.	0.	0.
	0.	-500.	0.
	0.	0.	200.
	-1000.	-500.	200.
2	-1000.	0.	0.
3	-2000.	0.	0.
4	-3000.	0.	0.

BOUNDARY

Boundary conditions along the panel edges (see Figure 2) are prescribed by the parameter IBCN(I), in which I denotes the panel edge number and the value of IBCN is 1,2,3, or 4 depending whether the edge is simply supported, clamped, free, or symmetric. Data for the examples follow:

Example Number	IBCN(1)	IBCN(2)	IBCN(3)	IBCN(4)
1,2,4	1	1	1	1
3	1	4	1	4

STIFFENER

Examples 2 and 3 include a blade type stringer, thus this subset must be included. A stiffener is defined by input for distinct stiffener segment widths WS(J), orientation of the widths in degrees relative to the Z direction of the panel, and a connective parameter. Input for a blade stringer is as follows:

```
1 1 0  WS(1)  1 0. 0
```

These data imply that there is one distinct stiffener segment width, one stringer segment, zero ring segments, the width of Segment 1 is WS(1), segment width number 1 is orientated in the positive Z direction, and segment number 1 is connected to the panel.

THICKNESS and WALL

These two sets describe the wall construction of the panel and stiffeners. Under the THICKNESS subset distinct layers are defined by a thickness, material angle, and material number for each load set. Under the WALL subset distinct wall constructions are defined based on the distinct layers. Then these distinct wall constructions are assigned to the panel and all distinct stiffener widths.

Three different wall constructions are used in the examples and are designated Wall 1, Wall 2, and Wall 3. Wall 1 is a single layer of an isotropic material. Wall 2 has four layers of an orthotropic material and is made symmetric about the midsurface of the wall thickness by the use of two distinct layer types. Wall 3 is also a composite with seven orthotropic material layers and is made symmetric about the midsurface of the wall thickness by four layer types.

Input for these subsets is given under the discussion of each example.

CONTROL

This is the subset in which the user specifies the analysis type (KANAL), structural analyser method (KSANA), optimizer (KOPTM), runstream type (KRUN), and four other parameters for the hardwired option (KCYCL, KSCYC, KPRINT, KDISPL). The analysis type can be a nonlinear static stress analysis, bifurcation buckling analysis, or an optimization analysis in which case KSANA = 0, 1, or 2. For structural analyzers FRITZ, SFRITZ, STAGS, or PASCO the parameter KANAL is -1, 0, 1, or 2. KOPTM is either 0 or 1. With KANAL = 0 or 1 KOPTM is set to 0, and with KANAL = 2 KOPTM is set to 1 for optimization with program CONMIN.

The runstream parameter (KRUN) designates whether (ECHO DATA) is on cards (KRUN=0 or 2) or on a file named DATE (KRUN=1 or 3) and whether the hardwired runstream for program OEXEC is to be used (KRUN=2 or 3). In the examples, the hardwired option is uses. Thus KRUN is either 2 or 3 depending on whether (ECHO DATA) is on cards or file. Following is a list of the above parameters and procedure file names:

Example/ Case	KANAL	KSANA	KOPTM	KRUN	Procedure File
1/A	1	2	0	2	(None)
1/B	2	2	1	2	ECHOCI
1/C	1	-1	0	3	ECHOGF
1/D	2	-1	1	3	ECHOGF
1/E	1	1	0	3	ECHOGF
1/F	2;1	-1;-1	1;0	3;3	ECHOGO
2,3,4	2	-1	1	3	ECHOGO

If the hardwired option is used then the parameters KCYCL, KSCYC, KPRINT, and KDISPL must be given appropriate values. With an optimization problem the value given to KCYCL is the maximum number of subsynthesis cycles, KSCYC denotes the number of subsynthesis cycles between computing new constraints (for STAGS type analyzers). This parameter is usually set to 1. Parameters KPRINT and KDISPL controls output to be printed. With KPRINT greater than zero output generated by the structural analyzer will be printed. The value of KDISPL designates the number of cycles between the printing of DISPLAY output from program OEXEC. The following list gives values used in the examples:

Example/ Case	KCYCL	KSCYC	KPRINT	KDISPL
1/A	0	0	1	0
1/B	10	0	0	0
1/C	0	0	2	0
1/D	10	1	0	1
1/E	0	0	2	0
1/F	20;0	1;0	0;2	1;0
2	15	1	0	1
3	15	1	0	1
4	20	1	0	1

CONSTRAINT

Data in this subset is used to define the constraint conditions to be imposed in an optimization problem (see Section 2.3). The choices of constraints at present are buckling, maximum strain, and maximum stress. If buckling is chosen then the mode separation parameter PHI must be given. For the two material constraint conditions allowable values must be given. Note that whenever PASCO is the analyzer (even in a buckling analysis problem) a material constraint condition must be imposed. Following are the parameters used to define the constraints and the allowable strains in the examples:

Example/ Case	NCTYP	KCTYP(1)	KCTYP(2)	PHI
1/A,1/B	2	1	2	1.0
1/D,1/F	1	1	-	1.0
2,3	1	1	-	1.0
4	2	1	2	1.0

Example/ Case	I=	EALLOW(1,I) 1	2	3	4	5
1/A,1/B		-1.	1.	-1.	1.	1.
4		-0.00452	0.00565	-0.0125	0.00320	0.0125

OPTIMIZE

This subset is only required for an optimization problem (KANAL=2). However, this set may be retained for other analysis types in which case the data are not used. Data supplied always consist of the five parameters SMOVE, SFACT, IPRINT, DELDV, and DDV. SMOVE and SFACT are defined by Equation 12; DELDV is defined by Equation 11; and DDV is defined by Equation 13. IPRINT controls output from the optimizer. With IPRINT=0, no output is printed.

Given the convergence criterion of Equation 13 and the subsynthesis move limits of Equation 12, the user can compute the maximum number of subsynthesis cycles which will satisfy Equation 13. For example, if SMOVE = 0.2, SFACT = 0.8, and DDV = 0.01 then convergence will always be satisfied after 15 cycles. When a material angle is a decision variable the move limits are restricted to values of five degrees and less. Even though convergence is satified, the user must be aware of the fact that the constraints may not be satified. Thus, inspection of the results is mandatory, and may suggest that the case must be restarted with the present values of the decision variables or that the optimization parameters be changed.

The value for DELDV should not be less than 0.002 with STAGS type structural analyzers. The default value in PASCO is 0.0005.

The following presents values of the five parameters used in the examples.

Example/ Case	SMOVE	SFACT	IPRINT	DELDV	DDV
1/B	0.2	0.8	0	.0001	.01
1/D	0.2	0.8	0	.005	.01
1/F	0.2	0.8	0	.005	.0005
2	0.2	0.8	0	.005	.01
3	0.2	0.8	0	.005	.01
4	0.2	0.8	0	.005	.0005

DECISION

The purpose of this set is to define which of the design variables (Equation 1) are fixed, decision, or linked by the vector IVN; to define the linking equations (Equation 2); and to define upper and lower bounds of the decision variables (Equation 7) in an optimization problem.

In Examples 1 and 4 there are no stiffeners; therefore, the set of design variables include the thicknesses and material angles of each distinct layer. With Wall 1, which is a single layer of an isotropic material, there is one distinct layer. Since changes in the material angle do not affect results, the thickness is the only possible decision variable. Thus the vector IVN = 1,0 defines the thickness as a decision variable and the material angle as being fixed in Example 1, Cases B and D. With Wall 2 (four layers of an orthotropic material) there are two distinct layers and therefore four possible design variables. Here IVN = 1,2,1,2 defines the thickness and material angle of Layer 1 as being decision variables and the thickness and material angle of Layer 2 as being linked. Hence, data for two linking equations must be included. With Wall 3 (seven layers of an orthotropic material) four distinct layers are defined, which give eight possible design variables. The problem is reduced to one in which there are two decision, four linked and two fixed variables by IVN = 1,2,2,2,0,1,2,0. This vector implies that the thicknesses of Layer 1 and material angle of Layer 2 are decision variables; thicknesses of Layers 2,3,4 and material angle of Layer 3 are linked variables; and material angles of Layers 1 and 4 are fixed variables.

In Examples 2 and 3, in which a blade stringer is included and in which the wall of both the panel and blade is a single isotropic layer (Wall 1), there are two distinct layers (for panel and stiffener) and one distinct stiffener segment width. IVN = 1,1,1,0,0 defines the width and thickness as being decision variables and the material angles as being fixed.

The linking equations and upper and lower bounds of the decision variables are given under the discussion of each example.

Note that the "DECISION" set must be included after sets STIFFENER and THICKNESS have been defined.

STAGS

This subset is required if the structural analyzer is FRITZ, SFRITZ, or STAGS (KANAL=1,0,or-1 in CONTROL set) and this is a buckling analysis (KSANA=1), optimization with buckling constraints (KSANA=2 and KCTYP(I)=1 in CONSTRAINT set), or a nonlinear analysis (KSANA=0). Note that for optimization with only stress or strain constraints this set is not required; however, KANAL must be 1,0, or -1.

The user must select models which correspond to general and local buckling loads, discretization, and modal functions with FRITZ and SFRITZ. Since these data are highly dependent on the problem, they are given under the discussion of each example.

END

The label END must always be provided by the user as the last record fo the (GEOMETRY DATA) set. After END is read the (GEOMETRY DATA) is processed and all data are written on the (GEOMERTY FILE) which has a local file name (lfn) of RDA. Control is then returned to the user for further instructions in the (ECHO DATA).

4.1.2 (ECHO DATA) Description

(ECHO DATA) consist of four data sets preceeded by the label HELP I, INPUT, OEXEC, or END.

(ECHO DATA) is only supplied by the user in Example 1 Cases A and B. This data set is contained in the procedure files for the other examples.

In Example 1, Case A for a buckling analysis with PASCO, (ECHO DATA) is as follows:

```
INPUT
1 0 0 0
(GEOMETRY DATA)
(EOR)
OEXEC
(EOR)
END
1 1
AP11
(EOR)
(EOF)
```

Under INPUT first card states that (GEOMETRY DATA) is on cards and follows, and that (OEXEC DATA), (GEOMETRY FILE), and (STATE FILE) are not required. After the (GEOMETRY DATA), the label OEXEC implies that the analysis is to be performed and that no data are required since this is a Hardwired PASCO analysis. After the analysis (under the END label) the (GEOMETRY FILE) is cataloged with the name AP11 for use with the other cases in Example 1.

In Example 1, Case B for the optimization with PASCO, (ECHO DATA) is as follows:

```
INPUT
1 0 2 0
AP11
(EOR)
(GEOMETRY DATA)
(EOR)
OEXEC
(EOR)
END
0
(EOF)
```

Under the label INPUT the first two cards inply that (GEOMETRY DATA) is on cards and that the (GEOMETRY FILE) is cataloged with the name AP11. Next comes the (GEOMETRY DATA) with changes to reflect that an optimization problem follows. As in the previous runstream the label OEXEC causes program ECHO to execute program OEXEC for the optimization. Under the label END the 0 implies that no files are to be cataloged and that no other problems are to be executed.

4.2 Example 1, Unstiffened Square Plate

The structure in this example is an untiffened, 10 inch square plate, simply supported along all edges, and loaded by four sets of inplane loads. Two wall constructions are included: Wall 1, a single layer of an isotropic material; and Wall 2, four layers of an orthotropic material.

Under this example six cases are considered. Cases A and B are buckling and optimization problems with Wall 1 using the program PASCO. Cases C and D are the same as A and B except that FRITZ is used as the structural analyzer. Case E is for a buckling analysis with Wall 1 with STAGS as the analyzer. Then Case F is for optimization and buckling analyses with Wall 2 and with use of FRITZ.

With Wall 1, all buckling analyses are performed for a thickness of 0.15 inches. This same thickness is used as the starting value in the optimization cases. Here the only decision variable is the plate thickness T(1).

For Wall 2 (Case F) there are four layers, two of which are distinct. The two distinct layers are linked in that the thickness of Layer 2 is equal to that of Layer 1 and the material angle (ZET(2)) of Layer 2 is set equal to the negative of that of Layer 1. The two required linking equations are

$$T(1) - T(2) = 0.$$
$$ZET(1) + ZET(2) = 720.$$

Note that the 720. is required, since 360. is added to the user input angle in order to avoid zero and negative angles. Here

there are two decision variables, T(1) and ZET(1), and two linked variables, T(2) and ZET(2).

When the structural analyzer FRITZ is employed, the user must specify model type, discretization (rows/columns), and modal functions. In this unstiffened panel problem, the model type can be 0, 1, 2, or 3. The number of rows/columns must be determined by a convergence study. Experience has shown that at least one node (row or column) must be included between each half wave and that a minimun of four nodes (rows or columns) is required for the integration process. In this problem the choice of modes is governed by the analytic solution of a square plate under shear given in Reference 12. Timoshenko shows that buckling under shear can be obtained by using sine functions in which the sum of the number of axial (m) and transverse (n) half wave is even. Thus, modes such as m,n= 1,1 ; 1,3 ; 3,1 ; 2,2 ; 3,3 should be used.

Input runstreams for the six cases are given in Tables 1-6. The runstream for Case A does not utilize a procedure file, and all input data are on cards. The (GEOMETRY FILE) is cataloged as AP11 for use with the other cases. In Case B the procedure file ECHOCI is used to reduce the number of control statements. Here the input data are also on cards. Note that the (GEOMETRY DATA) need only include data sets which are different from those used in Case A. Cases C, D, and E (Tables 3-5) have runstreams which utilize procedure file ECHOGF. Here changes to the (GEOMETRY DATA) of Case A are copied to a file DATG. With this procedure the user inputs (GEOMETRY DATA) since (ECHO DATA) is included in the procedure.

With Case F (Table 6) the procedure file ECHOGO is used. This procedure allows the user to input more than one set of (GEOMETRY DATA). In this case, an optimization problem is solved followed by a buckling analysis with the geometry obtained from the optimization. As seen in the table, the only changes for the analysis are in the sets TITLE, CONTROL, and DECISION. If the decision variables were not changed to fixed variables then buckling analyses would be given for three geometries under each of the four load sets.

Typical output from the ECHO option DISPLAY is shown in Table 7 for Example 1, Case D.

Results from the bifurcation analyses with Wall 1 are given in Table 8. Here eigenvalues are shown for each load set obtained from Reference 12, PANDA, PASCO, FRITZ, and STAGS. Also included are FRITZ analyses for other discretizations and modal function sets as well as STAGS analyses for other discretizations. Table 9 presents optimization results from program PANDA and program ECHO with analyzers PASCO and FRITZ. Convergence in these cases required two to three cycles and the resulting thicknesses varied in the fourth significant figure.

Table 10 shows optimization results for Case F which has Wall 2.

The two decision variables along with the total panel weight, eigenvalue for load set 4, and convergence value (CVX) are given as a function of cycle number. Here 15 cycles are required to reduce CVX to less than .0005 which is the input value for DVX. The L and U next to the angle denotes that the value is either an upper or lower bound in the subsynthesis. The final results are not significiently different from those obtained after four or five cycles.

4.3 Example 2, Blade Stiffened Square Plate

The same size square plate as in Example 1 is used. However, a single blade type stringer is inserted along the coordinate Y= 5.0 inches. Optimization of this configuration with all edges simply supported and subjected to an axial compressive load has been investigated by Libai (Reference 13). Libai shows that two local minimun weight designs exist which are designated "thick" and "thin." The term thick implies that the blade thickness is thicker than that for the "thin" case. Local buckling of the panel occurs with two half waves in both the X and Y directions. For the thick optimum, the blade is stable whereas this is not the situation for the thin optimum. A third case "simultaneous buckling" is also shown by Libai. Here the assumption is that the stiffener does not give support to the plate at the bifurcation buckling load. The absolute minimum weight design is that for the thick case. For the example under consideration Libai's results show that the optimum blade width to thickness ratio is about 2.0 for the thick case and about 18.0 for the thin and simultaneous cases.

Optimization for the thick and thin cases are solved using PASCO and FRITZ as well as the simultaneous case using FRITZ. The decision variables are the blade width WS(1), plate thickness T(1), and blade thicknes T(2). Starting values of these variables are close to the optimum values obtained by Libai.

Table 11 gives an input runstream for the thick, thin and simultaneous optimization problems using FRITZ as the structural analyzer. A runstream for optimization with PASCO involves changing the CONTROL set to (2 2 1 3 12 0 0 0), eliminating the STAGS set and including a stress or strain constraint (such as in Example 1, Case A, Table 1). The procedure file ECHOGO is used for this example to demonstrate input for multiple optimization problems without the need of cataloging data on a file as in Example 1, Case A.

Under the STAGS set for the thick case Model 0 is used to define general buckling and Model 2 is used for local buckling. Discretization into five rows and eleven columns is used for both models. The modal functions for Model 0 (general) include all three displacements W, V, U which have one axial half wave and five different odd numbers of transverse half waves (1,3,5,7,9) for a total of 15 modal functions. Model 2 (local) is 10.0 inches long, 5.0 inches wide, and contains a stringer along Y= 5.0 inches which has half the stiffness as that in Model 0. In

this model inplane displacements are not included. Thus the modal functions include only displacements in W which have two axial half waves and nine different transverse half waves making a total of nine functions. The use of the above discretization and modal functions was determined by a convergence study as shown in Table 12. Satisfactory results with less computer time could be achieved with a discretization of five rows, nine columns; and nine modes for Model 0, and five modes for Model 2. Note that the eigenvalue for Model 0 with 3 modes (one axial and one transverse halfwave) corresponds closely to that for a smeared stringer. Thus, including additional modal functions reduces the general buckling load to about 0.8 of the smeared value.

For the thin case, Model 4 is also included along with Models 0 and 2. Model 4 is for the buckling of the blade in which three edges are simply supported and the other is free. In the simultaneous case, the models are 0, 3 and 4.

Tables 13-15 show optimization results for the three cases utilizing FRITZ as the structural analyzer. The three decision variables, total weight, eigenvalues for each model, and convergence value CVX are given as functions of the subsynthesis cycle number. The total number of cycles was in these cases controlled by the convergence value DDV (in the OPTIMIZE subset) and not the maximum number of cycles KCYCL (in the CONTROL subset). Table 16 summarizes decision variables and weights obtained by Libai, PASCO, and FRITZ for the three cases. The agreement between these three analyses is good.

4.4 Example 3, Blade Stiffened Wide Plate

The problem considered in this example is the optimization of an infinitely wide plate, 10.0 inches in length (XL), stiffened by blade stringers every 7.5 inches and subjected to an axial compressive load (NXX) of -2000 lb/in. The loaded edges (Edges 1 and 3) are simply supported. The panel and blade are constructed of a single layer of an isotropic material (Wall 1).

This problem is treated with Fritz as the structural analyzer. Since the panel is infinitely wide the structural modeling considered for general buckling is that of a plate 7.5 inches wide (XT) and 10.0 inches long (XL), simply supported along Edges 1 and 3 and symmetry conditions along Edges 2 and 4. This model has stringers along Edges 2 and 4 which have half the stiffness of the actual blade. For local buckling, the boundary conditions are simple support along all edges of the model just described.

As in Example 2, this problem has at most three decision variables; blade width WS(1), plate thickness T(1), and blade thickness T(2). Here optimization is given for a thick and simultaneous case. Starting values of the decision variables are 1.0, 0.14, 0.2 for the thick case and 1.0, 0.14, 0.06 for the simultaneous case.

Table 17 gives an input runstream for the thick and simultaneous optimization problems (see Example 2). In the STAGS subset for the thick case, Model 0 is used for general buckling constraint and Model 2 is used for a local buckling constraint. Both models are discretized into five rows and seven columns. Nine modal functions are used for Model 0 and include all three displacement components, one axial half wave, and three even numbers of transverse half waves 0, 2, 4. Model 2 modal functions are all W displacement components with one and two axial half waves, and three odd numbers of transverse half waves 1, 3, 5. The functions were chosen after a convergence study was performed. Results of this study are shown in Table 18. Eigenvalues are given for the two models as a function of discretization and modal functions.

Models 0, 3, and 4 are used for the simultaneous case. Here the same modal functions are used for modal 0; modal 3 has one function with one axial and one transverse half wave and Model 4 has three functions with one axial half wave.

Tables 19 and 20 show optimization results for the two cases. Three decision variables, total weight, eigenvalues, and convergence value CVX are given as a function of cycle number. As in Example 2, the optimized structural weight for the simultaneoues case is about 5 percent higher than the thick case; however, the blade width-to-thickness ratios are extreamly different - 1.9 for the thick case and 17.0 for the simultaneous case.

Optimization results for this modeling of a wide plate are similar to those obtained for the 60.0 inch wide plate given in Example 2 of Reference 1 (see Table 2A). In Reference 1 the blade height, panel thickness, and blade thickness are 0.9202, 0.1397, 0.0571; whereas these values for the simultaneous case given here are 0.9070, 0.1396, 0.05803.

4.5 Example 4, Unstiffened Cylindrical Panel

The structure is a cylindrical panel constructed with seven layers of an orthotropic material (Wall 3), simply supported along all edges, and subjected to an axial compressive load (NXX) of -3000 lb/in. The panel is 30 inches in length (XL), has a radius of 80 inches, and subtends an angle of 17.19 degrees resulting in an arc length of 24 inches.

The layering is made symmetric about the midsurface of the wall thickness by use of four "distinct" layer types. The thicknesses of Layer Types 2, 3, and 4 are linked to Layer Type 1 such that Layer Types 2 and 3 are equal to Layer Type 1, and Layer Type 4 has twice the thickness as Layer Type 1 by the following equations:

$$T(1) - T(2) = 0.$$
$$T(1) - T(3) = 0.$$
$$2.*T(1) - T(4) = 0.$$

Material angles for Layer Types 1 and 4 are held fixed at 0.0 and 90.0 degrees while the angle ZET(3) is linked to ZET(2) by the equation

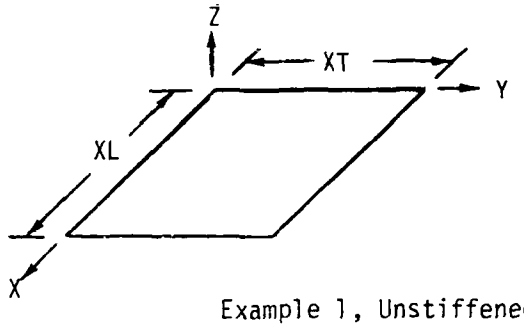
$$ZET(2) + ZET(3) = 720.$$

Thus this problem has two decision variables, T(1) and ZET(2), four linked variables, and two fixed variables making up a total of eight possible design variables.

Two constraint types are used: buckling and maximum strain. The parameter PHI (ratio between local and general buckling load) is set to one, and the maximum compressive and tensile strains in material directions 1 and 2 as well as the maximum shear strain are required input.

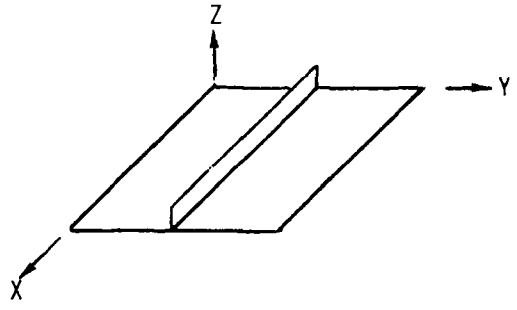
An input runstream for optimization with FRITZ is given in Table 21. Note that input values for the thickness of Layer 1 controls the other thicknesses and the angle for Layer 2 defines the angle of Layer 3 through the linking equations. Under the STAGS subset the input shows that the buckling constraint is determined by Model 3 (an unstiffened panel). The model is discretized into 5 rows and columns, the displacement components U, V are determined from equilibrium, and four modal functions have one and two axial and transverse half waves.

Table 22 shows the result of the optimization. Two cycles are required to bring the eigenvalue to 1.0 and after five cycles the user knows that the optimum angle is between 43.71 and 45.76 degrees. The remaing cycles suggest that the optimum angle is between 44.81 and 44.92 degrees which for practical purposes is 45.0 degrees.



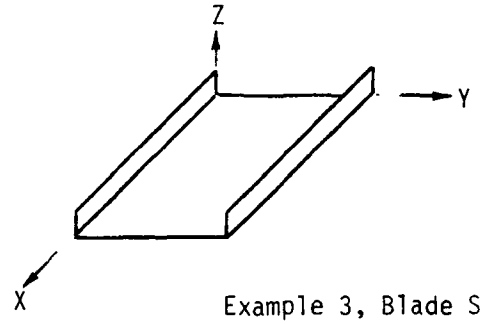
XL = XT = 10.0 in.
All edges simply
supported.

Example 1, Unstiffened Square Plate



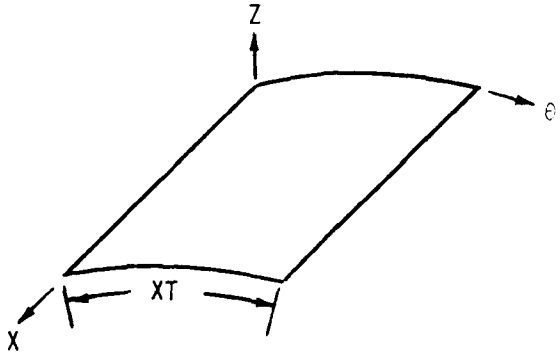
XL = XT = 10.0 in.
All edges simply
supported.

Example 2, Blade Stiffened Square Plate



XL = 10.0 in; XT = 7.5 in.
Edges 1, 3 simply supported.
Edges 2, 4 symmetry

Example 3, Blade Stiffened Wide Plate



XL = 30.0 in.; XT = 17.19 deg.
RA = 80.0 in.
All edges simply supported.

Example 4, Unstiffened Cylindrical Panel

Figure 4 Geometry of Example Problems

Table 1
Example 1, Case A, Input Runstream for Buckling Analysis with PASCO

```
(JOB CARD)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
ECHO(,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
EXIT(U)
(EOR)
INPUT
1 0 0 0
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,ANALYSIS,PASCO
PANEL
1 1 0 0
10. 10. 0.
BOUNDARY
1 1 1 1
LOAD
4
-1000. 0. 0.
0. -500. 0.
0. 0. 200.
-1000. -500. 200.
MATERIAL
1 10.+6 0. 0. 0.3 0.1 0. 0.
THICKNESS
1 4
.15 0. 1 1 1 1
WALL
1 0 0  1 1 1
CONTROL
1 2 0  2 0 0 1 0
CONSTRAINT
2 1 2  1.
-1. 1. -1. 1. 1.
END
(EOR)
OEXEC
(EOR)
END
1  1
AP11
(EOR)
(EOF)
```

(EOR) - End-of-Record Multipunch 789 in Column 1 of Card
(EOF) - End-of-File Multipunch 6789 in Column 1 of Card

Table 2
Example 1, Case B, Input Runstream for Optimization with PASCO

```
(JOB CARD)
BEGIN,ECHOCI,ECHOP.
(EOR)
INPUT
1 0 2 0
AP11
(EOR)
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,OPTIMIZE,PASCO
CONTROL
2 2 1
2 10 0 0 0
DECISION
1 0
1.0 0.1
OPTIMIZE
.2 .8 0 .0001 .01
END
(EOR)
OEXEC
(EOR)
END
0
(EOF)
```

Table 3
Example 1, Case C, Input Runstream for Buckling Analysis with FRITZ

```
(JOB CARD)
COPYBR(INPUT,DATG)
ATTACH(PD,AP11)
BEGIN,ECHOGF,ECHOP.
(EOR)
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,ANALYSIS,FRITZ
CONTROL
1 -1 0
3 0 0 2 0
STAGS
1  3  7 7  5
1 0 1 1  2 0 1 3  3 0 3 1  4 0 2 2  5 0 3 3
1 2 0
END
(EOF)
```

Table 4
Example 1, Case D, Input Runstream for Optimization with FRITZ

```
(JOB CARD)
COPYBR(INPUT,DATG)
ATTACH(PD,AP11)
BEGIN,ECHOGF,ECHOP.
(EOR)
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,OPTIMIZE,FRITZ
CONTROL
2 -1 1
3 10 1 0 1
STAGS
1  3  7 7  5
1 0 1 1  2 0 1 3  3 0 3 1  4 0 2 2  5 0 3 3
0 2 0
CONSTRAINT
1  1  1.
DECISION
1 0
1. .1
OPTIMIZE
.2 .8 0 .005 .01
END
(EOF)
```

Table 5
Example 1, Case E, Input Runstream for Buckling Analysis with STAGS

```
(JOB CARD)
COPYBR(INPUT,DATG)
ATTACH(PD,AP11)
BEGIN,ECHOGF,ECHOP.
(EOR)
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,ANALYSIS,STAGS
CONTROL
1 1 0
3 0 0 1 0
STAGS
1 3 11 11
END
(EOF)
```

Table 6
Example 1, Case F, Input Runstream for Optimization and Analysis with FRITZ

```
(JOB CARD)
COPYBF(INPUT,DATGR)
BEGIN,ECHOGO,ECHOP.
(EOR)
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 2,OPTIMIZE,FRITZ
CONTROL
2 -1 1  3 20 1 0 1
LOAD
4
-1000. 0. 0.
0. -500. 0.
0. 0. 200.
-1000. -500. 200.
PANEL
1 1 0 0   10. 10. 0.
BOUNDARY
1 1 1 1
MATERIAL
1   23.+6 1.7+6 .94+6 .304 .056 0. 0.
THICKNESS
2 4
.04  45. 1 1 1 1
.04 -45. 1 1 1 1
WALL
1 0 0
4
1 2 2 1  1
1
CONSTRAINT
1 1 1,
DECISION
1 2  1 2  2 3
1 1. 2 -1.  3 1. 4 1. 5 720.
1. 90.  .005 0.
OPTIMIZE
.2 .8  0 .005  .0015
STAGS
1  3  7 7  5
1 0 1 1  2 0 1 3  3 0 3 1  4 0 2 2  5 0 3 3
1 2 0
END
(EOR)
```

(Table continued on next page)

Table 6 (Continued)

```
TITLE
    EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 2,ANALYSIS,FRITZ
CONTROL
1 -1 0  3 0 0 2 0
DECISION
0 2  0 2  2 3
1 1. 2 -1.  3 1. 4 1. 5 720.
END
(EOF)
```

Table 7
Example 1, Case D, ECHO Display Output

```
------------------------------------------------------------------------
   DISPLAY STATE
EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,OPTIMIZE,FRITZ

------------------------------------------------------------------------
        APPLIED LOADS

              LOAD
              CASE       NXX          NYY          NXY
                1    -0.1000E+04 0.0000E+00 0.0000E+00
                2     0.0000E+00-0.5000E+03 0.0000E+00
                3     0.0000E+00 0.0000E+00 0.2000E+03
                4    -0.1000E+04-0.5000E+03 0.2000E+03

------------------------------------------------------------------------
        MATERIAL DATA
 MATERIAL
  NUMBER      E11          E22          E12       NU1    RHO     ALP1         ALP2
     1     0.1000E+08 0.0000E+00 0.0000E+000.30000.1000 0.0000E+00 0.0000E+0

------------------------------------------------------------------------
        BOUNDARY CONDITIONS
     BOUNDARY       BOUNDARY       BOUNDARY
     LOCATION       CONDITION       NUMBER
        I                           IBCN(I)
        1        SIMPLE SUPPORT       1
        2        SIMPLE SUPPORT       1
        3        SIMPLE SUPPORT       1
        4        SIMPLE SUPPORT       1

------------------------------------------------------------------------
        PANEL GEOMETRY

        FLAT PLATE     LENGTH=0.1000E+02      WIDTH=0.1000E+02

  WALL NUMBER=KWALP=  1

------------------------------------------------------------------------
        WALL LAYERING

   WALL  NUMBER   LAYER
 NUMBER LAYERS   NUMBER
    I   NLI(I)  LWALL(J,I),J=1,NLI(I)
    1      1      1,

------------------------------------------------------------------------
        WALL PROPERTIES

  LAYER  THICKNESS  DECISION   MATERIAL  DECISION  MATERIAL NUMBER
  NUMBER            VARIABLE    ANGLE    VARIABLE  MAT(I,L) L=LOAD CASE
     I      T(I)       KTN(I)   ZET(I)     KAN(I)   L=  1  2  3  4
     1   0.1500E+00    YES     0.0000E+00  FIXED          1  1  1  1
```

Table 7 (Continued)

```
---------------------------------------------------------------------------
   STATE OF DECISION VARIABLES

DECISION  PRESENT     START        INPUT VALUES          SUBSYNTHESIS
VARIABLE DECISION    DECISION     LOWER       UPPER      LOWER       UPPER
 NUMBER  VARIABLES  VARIABLES    BOUND       BOUND      BOUND       BOUND
    1   0.1500E+00 0.1500E+00 0.1000E+00 0.1000E+01 0.1000E+00 0.1000E+01

---------------------------------------------------------------------------
   OBJECTIVE FUNCTION (WEIGHT)= 0.1500E+01
   CONVERGENCE DATA
   CYCLE= 0 IDVV=0 CVX=0.000000E+00 DDV=0.000000E+00
   CONVERGENCE IS SATISFIED WHEN CVX<DDV-THEN IDVV IS SET TO 1.
   OPTIMIZE PARAMETERS
   SMOVE=0.200000E+00 SFACT=0.800000E+00 DELDV=0.500000E-02

---------------------------------------------------------------------------
         OPTIMIZATION CYCLE =     1
        OPTIMIZATION  PERFORMED
---------------------------------------------------------------------------
   DISPLAY STATE
EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,OPTIMIZE,FRITZ

---------------------------------------------------------------------------
        WALL PROPERTIES

  LAYER  THICKNESS  DECISION   MATERIAL  DECISION  MATERIAL NUMBER
  NUMBER            VARIABLE    ANGLE    VARIABLE  MAT(I,L) L=LOAD CASE
     I     T(I)       KTN(I)   ZET(I)     KAN(I)   L=  1  2  3  4
     1   0.1611E+00   YES     0.0000E+00  FIXED        1  1  1  1

---------------------------------------------------------------------------
   STATE OF DECISION VARIABLES

DECISION  PRESENT     START        INPUT VALUES          SUBSYNTHESIS
VARIABLE DECISION    DECISION     LOWER       UPPER      LOWER       UPPER
 NUMBER  VARIABLES  VARIABLES    BOUND       BOUND      BOUND       BOUND
    1   0.1611E+00 0.1500E+00 0.1000E+00 0.1000E+01 0.1200E+00 0.1800E+00

---------------------------------------------------------------------------
   OBJECTIVE FUNCTION (WEIGHT)= 0.1611E+01
   CONVERGENCE DATA
   CYCLE= 1 IDVV=0 CVX=0.738915E-01 DDV=0.100000E-01
   CONVERGENCE IS SATISFIED WHEN CVX<DDV-THEN IDVV IS SET TO 1.
   OPTIMIZE PARAMETERS
   SMOVE=0.200000E+00 SFACT=0.800000E+00 DELDV=0.500000E-02

---------------------------------------------------------------------------
   BUCKLING CONSTRAINT CONDITIONS

   CONSTRAINT  MODEL   FACTOR CONSTRAINT EIGENVALUE
     NUMBER     TYPE     PHI     VALUE
        1     LOCAL    1.0000-0.5071E+00 0.1507E+01
        2     LOCAL    1.0000-0.1999E+01 0.2999E+01
        3     LOCAL    1.0000-0.1677E+02 0.1777E+02
        4     LOCAL    1.0000 0.7451E-07 0.1000E+01

---------------------------------------------------------------------------
```

Table 7 (Continued)

```
        OPTIMIZATION CYCLE =     2
       OPTIMIZATION  PERFORMED


-------------------------------------------------------------------------

-------------------------------------------------------------------------
   DISPLAY STATE
EXAMPLE 1,SQUARE PLATE,UNSTIFFENED,WALL 1,OPTIMIZE,FRITZ

-------------------------------------------------------------------------
        WALL PROPERTIES

  LAYER  THICKNESS  DECISION   MATERIAL  DECISION  MATERIAL NUMBER
  NUMBER            VARIABLE    ANGLE    VARIABLE  MAT(I,L) L=LOAD CASE
     I     T(I)       KTN(I)   ZET(I)     KAN(I)   L=  1  2  3  4
     1   0.1611E+00   YES     0.0000E+00  FIXED         1  1  1  1

-------------------------------------------------------------------------
   STATE OF DECISION VARIABLES

DECISION  PRESENT     START        INPUT VALUES          SUBSYNTHESIS
VARIABLE DECISION   DECISION     LOWER      UPPER      LOWER      UPPER
 NUMBER  VARIABLES  VARIABLES    BOUND      BOUND      BOUND      BOUND
    1   0.1611E+00 0.1611E+00 0.1000E+00 0.1000E+01 0.1353E+00 0.1869E+00

-------------------------------------------------------------------------
   OBJECTIVE FUNCTION (WEIGHT)= 0.1611E+01
   CONVERGENCE DATA
   CYCLE= 2 IDVV=1 CVX=0.000000E+00 DDV=0.100000E-01
   CONVERGENCE IS SATISFIED WHEN CVX<DDV-THEN IDVV IS SET TO 1.
   OPTIMIZE PARAMETERS
   SMOVE=0.200000E+00 SFACT=0.800000E+00 DELDV=0.500000E-02

-------------------------------------------------------------------------
   BUCKLING CONSTRAINT CONDITIONS

   CONSTRAINT  MODEL   FACTOR CONSTRAINT EIGENVALUE
     NUMBER     TYPE     PHI    VALUE
        1     LOCAL    1.0000-0.5113E+00 0.1511E+01
        2     LOCAL    1.0000-0.2023E+01 0.3023E+01
        3     LOCAL    1.0000-0.1682E+02 0.1782E+02
        4     LOCAL    1.0000-0.4424E-02 0.1004E+01

-------------------------------------------------------------------------
```

Table 8
Example 1, Results of Buckling Analyses with Wall 1

Case	Structural Analyzer	Rows/ Columns	Number of Modes	Eigenvalues for load set I - E(I) E(1)	E(2)	E(3)	E(4)
	Analytic	-	-	1.220	2.440	14.25	---
	PANDA	-	-	1.220	2.440	8.875	0.8030
A	PASCO	-	-	1.220	2.440	8.422	0.8038
	FRITZ	4/4	5	1.220	2.440	15.18	0.8110
		5/5	5	1.220	2.440	14.36	0.8110
C		7/7	5	1.220	2.440	14.38	0.8109
		9/9	5	1.220	2.440	14.37	0.8109
		9/9	8	1.220	2.440	14.35	0.8108
		9/9	11	1.220	2.440	14.31	0.8108
		11/11	8	1.220	2.440	14.34	0.8108
		11/11	11	1.220	2.440	14.30	0.8108
		13/13	11	1.220	2.440	14.30	0.8108
	STAGS	7/7	-	1.198	2.390	13.72	0.7960
		9/9	-	1.208	2.415	13.92	0.8023
E		11/11	-	1.212	2.424	14.03	0.8054

Table 9
Example 1, Optimization Results with Wall 1

Case	Structural Analyzer	T(1) in.	Weight lbs.
	PANDA	0.1614	1.614
B	PASCO	0.1613	1.613
D	FRITZ	0.1611	1.611

Table 10
Example 1, Optimization Results with Wall 2 (Case F)

Cycle Number	T(1) in. 10-1	ZET(1) degrees		Weight lbs.	E(3)	CVX 10-2
0	0.4000	45.00		0.8960	0.9018	---
1	0.4129	40.00	L	0.9249	0.9825	2.23
2	0.4136	44.00	U	0.9264	0.9973	0.58
3	0.4134	40.80	L	0.9259	0.9889	0.42
4	0.4141	43.36	U	0.9276	1.0024	0.41
5	0.4139	41.31	L	0.9272	0.9937	0.27
6	0.4143	42.95	U	0.9280	1.0031	0.25
7	0.4142	44.26	U	0.9279	1.0039	0.17
8	0.4141	43.21	L	0.9275	0.9989	0.15
9	0.4142	42.37	L	0.9277	1.0001	0.11
10	0.4141	43.04	U	0.9276	0.9969	0.09
11	0.4142	43.58	U	0.9279	1.0026	0.09
12	0.4139	43.15	L	0.9270	1.0005	0.10
13	0.4138	42.81	L	0.9269	0.9963	0.06
14	0.4142	43.08	U	0.9279	1.0011	0.09
15	0.4142	43.30	U	0.9279	1.0004	0.03

E(3) - Eigenvalue for Load Case 3
CVX - Convergence Value (Equation 13)

Table 11
Example 2, Input Runstream for Optimization with FRITZ

```
(JOB CARD)
COPYBF(INPUT,DATGR)
BEGIN,ECHOGO,ECHOP.
(EOR)
TITLE
    EXAMPLE 2,SQUARE PLATE,BLADE STRINGER,THICK,OPTIMIZE,FRITZ
CONTROL
2 -1 1  3 12 1 0 1
MATERIAL
1 10.+6 0. 0. .3 .1 0. 0.
LOAD
1 -1000. 0. 0.
PANEL
1 1 1 0
10. 10. 0.
BOUNDARY
1 1 1 1
THICKNESS
2 1
.078 0. 1
.25 0. 1
STIFFENER
1 1 0
.46
1 0. 0
WALL
2 1 0  1 1  1 2  1 2
CONSTRAINT
1 1  1.
DECISION
1  1 1  0 0
2. 1. 1.  .1 .01 .01
OPTIMIZE
.2 .8  0 .005  .01
STAGS
2  0 2  5 11 5 11  15 9
1 3 1 1  2 2 1 1  3 1 1 1
4 3 1 3  5 2 1 3  6 1 1 3
7 3 1 5  8 2 1 5  9 1 1 5
10 3 1 7  11 2 1 7  12 1 1 7
13 3 1 9  14 2 1 9  15 1 1 9
1 3 2 1  2 3 2 2  3 3 2 3  4 3 2 4  5 3 2 5
6 3 2 6  7 3 2 7  8 3 2 8  9 3 2 9
0 2 0
END
(EOR)
```

(Table continued on next page)

Table 11 (Continued)

```
TITLE
    EXAMPLE 2,SQUARE PLATE,BLADE STRINGER,THIN ,OPTIMIZE,FRITZ
THICKNESS
2 1
.088 0. 1
.04 0. 1
STIFFENER
1 1 0
.74
1 0. 0
STAGS
3  0 2 4  5 11 5 11 5 4  15 9 3
1 3 1 1  2 2 1 1  3 1 1 1
4 3 1 3  5 2 1 3  6 1 1 3
7 3 1 5  8 2 1 5  9 1 1 5
10 3 1 7  11 2 1 7  12 1 1 7
13 3 1 9  14 2 1 9  15 1 1 9
1 3 2 1  2 3 2 2  3 3 2 3  4 3 2 4  5 3 2 5
6 3 2 6  7 3 2 7  8 3 2 8  9 3 2 9
1 3 2 2  2 3 2 3  3 3 2 4
0 2 0
END
(EOR)
TITLE
    EXAMPLE 2,SQUARE PLATE,BLADE STRINGER,SIMUL,OPTIMIZE,FRITZ
THICKNESS
2 1
.088 0. 1
.04 0. 1
STIFFENER
1 1 0
.74
1 0. 0
STAGS
3  0 3 4  5 11 5 4 5 4  15 1 3
1 3 1 1  2 2 1 1  3 1 1 1
4 3 1 3  5 2 1 3  6 1 1 3
7 3 1 5  8 2 1 5  9 1 1 5
10 3 1 7  11 2 1 7  12 1 1 7
13 3 1 9  14 2 1 9  15 1 1 9
1 0 2 1
1 3 2 2  2 3 2 3  3 3 2 4
0 2 0
END
(EOF)
```

Table 12
Example 2, Buckling Analysis Results for
Models 0 and 2

Model 0			Model 2		
Rows/ Columns	Number of Modes	E(0)	Rows/ Columns	Number of Modes	E(2)
5/9	3	1.3526	5/9	1	1.6230
5/9	6	1.0948	5/9	3	1.1524
5/9	9	1.0648	5/9	5	1.1000
5/9	12	1.0546	5/9	7	1.0793
5/9	15	1.0486	5/9	9	1.0726
5/11	15	1.0497	5/11	9	1.0682
5/13	15	1.0497	5/13	9	1.0682

E(K) - Eigenvalue for Model K

Table 13
Example 2, Optimization Results for Thick Case

Cycle Number	WS(1) in.	T(1) in. 10-1	T(2) in.		Weight lbs.	E(0)	E(2)	CVX 10-2
0	0.4600	0.7800	0.2500		0.8950	1.0490	1.0680	---
1	0.4682	0.7729	0.2000	L	0.8666	0.9551	0.9559	7.56
2	0.4591	0.7650	0.2320	U	0.8715	0.9832	0.9858	6.33
3	0.4692	0.7782	0.2023	L	0.8731	0.9727	0.9784	5.58
4	0.4810	0.7934	0.1816	L	0.8807	0.9841	0.9878	4.90
5	0.4776	0.7904	0.1965	U	0.8842	1.0074	1.0092	3.09
6	0.4700	0.7788	0.2093	U	0.8772	0.9937	0.9945	3.21
7	0.4671	0.7731	0.2203	U	0.8761	1.0007	0.9959	2.19
8	0.4701	0.7771	0.2111	L	0.8763	0.9955	0.9924	1.78
9	0.4673	0.7746	0.2182	U	0.8766	0.9978	0.9961	1.42
10	0.4646	0.7722	0.2240	U	0.8763	0.9978	0.9983	1.19
11	0.4662	0.7743	0.2192	L	0.8765			0.92

E(K) - Eigenvalue for Model K

Table 14
Example 2, Optimization Results for Thin Case

Cycle Number	WS(1) in.	T(1) in. 10-1	T(2) in. 10-1	Weight lbs.	E(0)	E(2)	E(4)	CVX 10-2
0	0.7400	0.8800	0.4000	0.9096	1.0510	1.0240	1.0750	-.--
1	0.7350	0.8731	0.3802	0.9010	0.9979	0.9973	0.9788	2.14
2	0.7337	0.8739	0.3832	0.9020	0.9998	1.0000	0.9747	0.35
3	0.8276U	0.8568	0.4322U	0.8926	1.2988	0.9549	1.0022	9.19
4	0.7428L	0.8701	0.3879L	0.8990	1.0261	0.9892	1.0042	7.35
5	0.7428	0.8734	0.3879	0.9022				0.13

E(K) - Eigenvalue for Model K

Table 15
Example 2, Optimization Results for Simultaneous Case

Cycle Number	WS(1) in.	T(1) in. 10-1	T(2) in. 10-1	Weight lbs.	E(0)	E(3)	E(4)	CVX 10-2
0	0.7400	0.8800	0.4000	0.9096	1.0510	1.0191	1.0750	---
1	0.7347	0.8743	0.3796	0.9022	0.9988	0.9977	0.9661	2.15
2	0.7316	0.8762	0.3843	0.9043	0.9996	1.0037	1.0113	0.62
3	0.7326	0.8762	0.3826	0.9042				0.19

E(K) - Eigenvalue for Model K

Table 16
Example 2, Summary of Optimization Results

Type	Structural Analyzer	WS(1) in.	T(1) in.	T(2) in.	Weight lbs.
Thick	Ref.13	0.4600	0.07700	0.2450	0.8827
	PASCO	0.4640	0.07778	0.2332	0.8860
	FRITZ	0.4662	0.07743	0.2192	0.8765
Thin	Ref.13	0.7200	0.08750	0.04000	0.9038
	PASCO	0.8465	0.08780	0.02632	0.9003
	FRITZ	0.7428	0.08734	0.03879	0.9022
Simul	Ref.13	0.7400	0.08800	0.04000	0.9096
	FRITZ	0.7326	0.08762	0.03826	0.9042

Table 17
Example 3, Input Runstream for Optimization with Fritz

```
(JOB CARD)
COPYBF(INPUT,DATGR)
BEGIN,ECHOGO,ECHOP.
(EOR)

TITLE
    EXAMPLE 3,WIDE PLATE,BLADE STRINGERS,THICK,OPTIMIZE,FRITZ
CONTROL
2 -1 1  3 15 1 0 1
LOAD
1 -2000. 0. 0.
MATERIAL
1 10.+6 0. 0. .3 .1 0. 0.
BOUNDARY
1 4 1 4
PANEL
2 1 0 0
10. 7.5 0.
STIFFENER
1 1 0
1.0
1 0. 0
THICKNESS
2 1
.14 0. 1
.2 0. 1
WALL
2 1 0  1 1  1 2  1 2
CONSTRAINT
1 1  1.
DECISION
1  1 1  0 0
5. .5 .5  .1 .01 .01
OPTIMIZE
.2 .8  0 .005  .01
STAGS
2  0 2  5 7 5 7  9 6
1 3 1 0  2 2 1 0  3 1 1 0
4 3 1 2  5 2 1 2  6 1 1 2
7 3 1 4  8 2 1 4  9 1 1 4
1 3 1 1  2 3 1 3  3 3 1 5
4 3 2 1  5 3 2 3  6 3 2 5
0 2 0
END
(EOR)
```

(Table continued on next page)

Table 17 (Continued)

```
TITLE
    EXAMPLE 3,WIDE PLATE,BLADE STRINGERS,SIMUL,OPTIMIZE,FRITZ
STIFFENER
1 1 0
1.0
1 0. 0
THICKNESS
2 1
.14 0. 1
.06 0. 1
STAGS
3  0 3 4  5 7 5 4 5 4  9 1 3
1 3 1 0  2 2 1 0  3 1 1 0
4 3 1 2  5 2 1 2  6 1 1 2
7 3 1 4  8 2 1 4  9 1 1 4
1 0 1 1
1 3 1 2  2 3 1 3  3 3 1 4
0 2 0
END
(EOF)
```

Table 18
Example 3, Results of Buckling Analyses
for Models 0 and 2

Model 0			Model 2			
Rows / Columns	Number of Modes	E(0)	Rows / Columns	Number of Modes	E(2) 1 axial	E(2) 2 axial
5/7	3	4.0247	5/7	2	1.4248	1.5177
5/7	6	2.0885	5/7	4	1.4080	1.4714
5/7	9	2.0237	5/7	6	1.4022	1.4557
5/7	12	2.0043	5/7	8	1.4012	1.4524
5/9	12	2.0073	5/9	8	1.3993	1.4480

E(K) - Eigenvalue for Model K

Table 19
Example 3, Optimization Results for Thick Case

Cycle Number	WS(1) in.	T(1) in.	T(2) in.		Weight lbs.	E(0)	E(2)	CVX 10-2
0	1.0000	0.1400	0.2000		1.250	2.0237	1.4022	---
1	0.8000L	0.1187	0.2400	U	1.082	1.2457	1.0135	18.4
2	0.6720L	0.1158	0.2784	U	1.056	1.0021	0.9899	11.5
3	0.6591	0.1123	0.3140	U	1.049	0.9919	0.9831	5.93
4	0.6661	0.1156	0.2819	L	1.055	0.9928	0.9908	4.75
5	0.6604	0.1135	0.3050	U	1.053	0.9950	0.9918	3.61
6	0.6540	0.1119	0.3250	U	1.052	0.9932	0.9924	2.97
7	0.6585	0.1134	0.3079	L	1.053	0.9940	0.9940	2.41
8	0.6553	0.1123	0.3208	U	1.052	0.9941	0.9934	1.88
9	0.6529	0.1115	0.3316	U	1.053	0.9958	0.9946	1.46
10	0.6504	0.1111	0.3405	U	1.054	0.9981	0.9993	1.16
11	0.6488	0.1105	0.3478	U	1.054			0.96

E(K) - Eigenvalue for Model K

Table 20
Example 3, Optimization Results for Simultaneous Case

Cycle Number	WS(1) in.	T(1) in.	T(2) in. 10-1		Weight lbs.	E(0)	E(3)	E(4)	CVX 10-2
0	1.0000	0.1400	0.6000		1.110	1.0504	1.0117	1.0508	---
1	0.9917	0.1393	0.5703		1.102	0.9957	0.9934	0.9430	2.08
2	1.150	U 0.1366	0.6615		1.100	1.3784	0.9549	0.9629	11.3
3	1.003	L 0.1381	0.5768	L	1.093	1.0148	0.9692	0.9500	8.91
4	1.106	U 0.1376	0.6359	U	1.102	1.2769	0.9703	0.9537	6.96
5	1.015	L 0.1386	0.5953		1.100	1.0638	0.9805	0.9912	5.12
6	0.9863	0.1394	0.5801		1.103	0.9970	0.9965	1.0030	1.98
7	0.9870	0.1396	0.5803		1.104				0.08

E(K) - Eigenvalue for Model K

Table 21
Example 4, Input Runstream for Optimization with FRITZ

```
(JOB CARD)
COPYBF(INPUT,DATGR)
BEGIN,ECHOGO,ECHOP.
(EOR)
TITLE
  EXAMPLE 4,CYLINDRICAL PANEL,COMPOSITE, OPTIMIZE,FRITZ
CONTROL
2 -1 1  3 20 1 0 1
LOAD
1  -3000. 0. 0.
MATERIAL
1  23.+6 1.7+6 .94+6 .304 .056 0. 0.
BOUNDARY
1 1 1 1
PANEL
1 2 0 0
30. 17.19 80.
THICKNESS
4 1
.04 0. 1
.04 36. 1
.005 -45. 1
.02 90. 1
WALL
1 0 0
7  1 2 3 4 3 2 1  1
CONSTRAINT
2  1 2  1.
-.00452  .00565  -.0125  .0032  .0125
DECISION
1 2 2 2  0 1 2 0
2 2 2 3
1 1. 2 -1.  1 1. 3 -1.  1 2. 4 -1.  6 1. 7 1. 9 720.
5. 180.  .005 -180.
OPTIMIZE
.2 .8  0 .005  .0005
STAGS
1  3  5 5  4
1 0 1 1  2 0 1 2  3 0 2 1  4 0 2 2
0 2 0
END
(EOF)
```

Table 22
Example 4, Optimization Results

Cycle Number 10-1	T(1) in.		ZET(2) degrees		Weight lbs.	E(3) 10-2	CVX
0	0.4000		36.00		12.90	2.4326	----
1	0.3200	L	36.00		10.32	1.4359	10.00
2	0.2735		40.00	U	8.821	1.0209	7.77
3	0.2693		43.20	U	8.687	0.9977	1.16
4	0.2690		45.76	U	8.677	1.0005	0.37
5	0.2689		43.71	L	8.674	0.9956	0.27
6	0.2692		45.35	U	8.682	1.0021	0.25
7	0.2691		44.04	L	8.681	0.9967	0.17
8	0.2692		45.09	U	8.683	1.0011	0.14
9	0.2691		44.25	L	8.682	0.9971	0.11
10	0.2692		44.92	U	8.685	1.0000	0.10
11	0.2692		44.38	L	8.685	1.0008	0.07
12	0.2692		44.81	U	8.685	1.0000	0.06
13	0.2692		45.16	U	8.685		0.04

E(K) - Eigenvalue for Model K

SECTION 5

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APPENDIX A

INPUT DATA REQUIREMENTS FOR ECHO

A.1 General

Input requirements for programs ECHO and OEXEC of the ECHO program system are presented in this Appendix. Figure 3 shows the operations performed by these two programs. Program ECHO is essentially a preprocessor. All operations related to a structural analysis and optimization are performed in program OEXEC. Input to these programs is structured so that the user can perform the designated operations in a manner to satisfy special needs. For example, only the HELP operation in program ECHO can be executed. The order in which operations are performed is not completely arbitrary in that the INPUT operation must occur prior to the OEXEC operation (execution of program OEXEC).

Input data supplied by the user consist of data for program ECHO which are called (ECHO DATA); data for program OEXEC which are called (OEXEC DATA); and data which defines the structure, boundary conditions, loading, optimization parameters, and the analysis type which are called (GEOMETRY DATA). See Sections A.2, A.3, and A.4 for descriptions of these data sets.

(ECHO DATA) is always required. However, (GEOMETRY DATA) and/or (OEXEC DATA) may not be required for certain applications. The following discussion on the program operation should aid the user in understanding the input requirements and control cards.

A.1.1 Operation

On the CDC NOS/BE operating system, program ECHO is executed by the following control statement

```
ECHO(INPUT,OUTPUT,PF,HEP,RDA,STA)
```

in which INPUT is the input file, OUTPUT is the output file, PF is a local "procedure file", HEP is a file containing information about ECHO, RDA is a file defining the problem, and STA is a file containing information from the optimizer.

On CDC, INPUT is a special file in which input data are on cards following all control statements and separated by an END-OF- RECORD mark. Here, INPUT refers to the (ECHO DATA) which can be on cards or a file with a local file name (LFN) of DATE. The output file is on TAPE6 and the input file is on TAPE5. When (ECHO DATA) is on cards, ECHO is executed by the control statement

```
ECHO(,,PF,HEP,RDA,STA)
```

and when (ECHO DATA) is on file DATE, the control statement is

```
ECHO(DATE,,PF,HEP,RDA,STA) .
```

If (ECHO DATA) is on a cataloged file with the name MYFILE, then this file must be attached by the user with a LFN of DATE by the control statement

ATTACH(DATE,MYFILE)

prior to the ECHO execution statement.

RDA is the LFN for a file which will be called (GEOMETRY FILE) and STA is the LFN for a file which will be called (STATE FILE). In an initial structural analysis or optimization these two files do not exist. Upon execution of ECHO with the INPUT operation in (ECHO DATA), (GEOMETRY DATA) is read and written on, (GEOMETRY FILE). This (GEOMETRY FILE) can be cataloged after the INPUT operation by the END operation or can be used to define an analysis problem in OEXEC. At the end of a subsynthesis cycle in an optimization analysis, values of the decision variables, weight, constraint equations, subsynthesis cycle number, and convergence criterion are written on the (STATE FILE). At the beginning of a new cycle the (GEOMETRY FILE) is updated with respect to the decision variables. The (GEOMETRY FILE) and (STATE FILE) can be cataloged at the end of each cycle in OEXEC, at the end of a case in ECHO, or by the user (with approproiate control statements).

All problems which can be treated by programs ECHO and OEXEC are completely defined by (ECHO DATA), (OEXEC DATA), (GEOMETRY DATA), (GEOMETRY FILE), and (STATE FILE). As stated previously the (ECHO DATA) can be on cards or a file which has been attached with the LFN of DATE. The (OEXEC DATA), if needed, can be on cards with the (ECHO DATA) or on a file which has been attached by the user with the LFN of DATO. The (GEOMETRY DATA), if needed, can be on cards with the (ECHO DATA) or on a file which has been attached by the user with the LFN of DATG. The (GEOMETRY FILE) and (STATE FILE), if needed, can be attached by operations in program ECHO or by the user. If attached by the user the LFN of the (GEOMETRY FILE) must be RDA and the LFN of the (STATE FILE) must be STA. The (STATE FILE) is only needed for a restart of an optimization problem in which the starting cycle number is indexed by one. Without the (STATE FILE) the cycle number starts at zero.

Execution of program OEXEC proceeds via control statements in the "procedure file" PF generated in ECHO. Therefore, the user need not supply control statements for execution of OEXEC.

A.2 INPUT DATA FOR PROGRAM ECHO (ECHO DATA)

The purpose of program ECHO is to

1. provide information about the ECHO system
2. provide methods to input data
3. execute program OEXEC
4. catalog files generated by ECHO and OEXEC.

(ECHO DATA) consists of four data sets. The first card of a set is a label. The four sets are referred to by the labels: HELP I, INPUT, OEXEC, and END. These data sets can be on either a permanent file or data cards.

A number of labels HELP I may be included (in which I is substituted by an integer, I=1,2--7). In each of these requests, some information about the program is printed. No further input data are included under these labels.

Under the label INPUT, information is given about the form of the input followed by a definition of the problem given in (GEOMETRY DATA).

Under the label OEXEC, data are given to define the flow of computations and file manipulation. (OEXEC DATA) is not required whenever a standard hardwired option is used. (OEXEC DATA) can be stored on a file with LFN of DATO.

Under the label END, requests may be made to catalog files.

The entire sequence of input data for ECHO can be stored on a file with a LFN of DATE.

DATA FORMAT-

Numerical data are read in CDC free FORMAT. Zeros can not be replaced by blanks and all input values in a list must be given. File names are read in FORMAT A10. If more than one name is required, each name must be on a separate card. Labels of data sets must start in Column 1. (EOR) is an END-OF-RECORD mark which corresponds to a 789 punch in Column 1 on a card. (EOF) is an END-OF-FILE mark which corresponds to a 6789 punch in Column 1 on a card.

The ECHO input is described in the following. First the parameters included under the different labels are listed. Then follows an explanation of each of these parameters.

A.2.1 LIST OF (ECHO DATA)

```
HELP I                    (REPEAT AS DESIRED FOR VARIOUS VALUES OF
                           I)
INPUT
   (LD(I),I=1,4)
   (FILEI(I))             (INCLUDE IF LD(I)=2 OR -2, FORMAT A10,
   ('''''''')              MAXIMUM OF 4 SEPARATE CARDS)
   (EOR)                  (INCLUDE IF LD(I)=2 OR IF LD(1)=-2)
   (GEOMETRY DATA)        (INCLUDE IF LD(1)=1 OR -1)
   (EOR)
OEXEC
   (EOR)
   (OEXEC DATA)           (INCLUDE IF LD(2)=1 OR -1)
   (EOR)                  (INCLUDE IF LD(2)=1 OR -1)
END
   (NFIL)
   (LD(I),I=1,NFIL)       (INCLUDE IF NFIL>0)
   (FILEI(I))             (INCLUDE IF LD(I)>0)
   ('''''''')             (MAXIMUM OF 2 CARDS,
                           FORMAT A10)
   (EOR)                   (INCLUDE IF NFIL>0)
   (EOF)                  (INCLUDE IF LAST CASE)
```

A.2.2 DESCRIPTION OF (ECHO DATA)

INFORMATION ABOUT THE SETS HELP I, INPUT, OEXEC, AND END FOLLOWS.

HELP I SET

VARIOUS TYPES OF INFORMATION ABOUT ECHO IS PRINTED DEPENDING ON THE VALUE OF I IN THE LABEL HELP I. FOLLOWING IS THE INFORMATION TYPE OBTAINED WITH OPTIONS OF I:

```
HELP      ECHO DESCRIPTION
HELP 1    PROGRAM ECHO  INPUT REQUIREMENTS  (ECHO DATA)
HELP 2    PROGRAM OEXEC INPUT REQUIREMENTS  (OEXEC DATA)
HELP 3    INPUT REQUIREMENTS FOR (GEOMETRY DATA)
HELP 4    PROCEDURE FILES FOR EXECUTION OF ECHO
HELP 5    EXAMPLES
HELP 6    FIRST TIME USERS
HELP 7    ADDITIONAL INFORMATION AND UPDATES
```

ORDERING OF THE DATA SET IS NOT NECESSARY,THUS A SET MAY BE

```
HELP 2
HELP
HELP 1
```

INPUT SET

THIS SET OF DATA INFORMS ECHO AS TO THE LOCATION AND STATUS OF THE INPUT DATA FOR ECHO AND OEXEC. ALL REQUIRED (GEOMETRY DATA) IS INPUT AT THIS POINT. AFTER BEING READ, THE (GEOMETRY DATA) IS WRITTEN ON THE (GEOMETRY FILE) , WITH THE LOCAL NAME OF RDA.

THE INPUT SET CONSISTS OF THE FOLLOWING DATA:

```
INPUT
   (LD(I),I=1,4)
   (FILEI(I))            (INCLUDE IF LD(I)=2 OR -2, FORMAT A10,
   ('''''''')            MAXIMUM OF 4 SEPARATE CARDS)
   (EOR)                 (INCLUDE IF LD(I)=2 OR IF LD(1)=-2)
   (GEOMETRY DATA)       (INCLUDE IF LD(1)=1 OR -1)
   (EOR)
```

NOTATION	DESCRIPTION
LD(1)	STATUS OF (GEOMETRY DATA) = 0 NOT NEEDED = 1 ON CARDS =-1 ON FILE DATE =-2 ON CATALOGED FILE (FILE HAS BEEN ATTACHED BY USER)
LD(2)	STATUS OF (OEXEC DATA) SAME CODE AS FOR LD(1)
LD(3)	STATUS OF (GEOMETRY FILE) = 0 NOT NEEDED = 2 ON CATALOGED FILE (FILE TO BE ATTACHED BY ECHO) =-2 ON CATALOGED FILE (FILE HAS BEEN ATTACHED BY USER)
LD(4)	STATUS OF (STATE FILE) SAME CODE AS FOR LD(3)
FILEI(1)	DATG (INCLUDE IF LD(1)=-2)
FILEI(2)	DATO (INCLUDE IF LD(2)=-2)
FILEI(3)	FILE NAME FOR (GEOMETRY FILE) (INCLUDE IF LD(3)= 2) RDA (INCLUDE IF LD(3)=-2)
FILEI(4)	FILE NAME FOR (STATE FILE) (INCLUDE IF LD(4)= 2) STA (INCLUDE IF LD(4)=-2)

COMMENTS ON INPUT SET

INPUT DATA FOR PROGRAM ECHO CAN BE ON CARDS OR FILE DATE.
THESE LOCATIONS OF THE DATA CORRESPOND TO THE VALUE OF (KRUN) IN THE (GEOMETRY DATA).
IF KRUN=0 OR 2 (ECHO DATA) IS ON CARDS
=1 OR 3 (ECHO DATA) IS ON FILE (DATE) WHICH MUST BE ATTACHED PRIOR TO EXECUTION OF ECHO
NOTE THAT DATE, DATG, DATO, RDA, AND STA ARE LOCAL FILE NAMES.

OEXEC SET

THIS DATA SET PROVIDES THE MEANS TO EXECUTE PROGRAM OEXEC FOR THE ANALYSIS OR OPTIMIZATION OF A STIFFENED PANEL DEFINED BY THE (GEOMETRY DATA). AFTER READING OEXEC, PROGRAM OEXEC IS ATTACHED AND EXECUTED WITH THE (OEXEC DATA). DURING AN OPTIMIZATION CYCLE THE STATE OF THE DESIGN VARIABLES ARE WRITTEN ON THE (STATE FILE) WHICH HAS THE LOCAL NAME STA.

THE OEXEC SET CONSISTS OF THE FOLLOWING DATA:

```
OEXEC
   (EOR)
   (OEXEC DATA)          (INCLUDE IF LD(2)=1 OR -1)
   (EOR)                 (INCLUDE IF LD(2)=1 OR -1)
```

COMMENTS ON OEXEC SET

IF KRUN=2 OR 3 IN THE (GEOMETRY DATA), THEN (OEXEC DATA) IS NOT REQUIRED. SEE SECTION A.3 FOR A DESCRIPTION OF (OEXEC DATA).

END SET

THIS SET PROVIDES AN OPTION TO CATALOG THE (GEOMETRY FILE) AND / OR THE (STATE FILE). IF NFIL=0 NO FILES ARE CATALOGED.

THE END SET CONSISTS OF THE FOLLOWING DATA:

```
END
   (NFIL)
   (LD(I),I=1,NFIL)      (INCLUDE IF NFIL>0)
   (FILEI(I))            (INCLUDE IF LD(I)>0)
   ('''''''''')          (MAXIMUM OF 2 CARDS,
                          FORMAT A10)
   (EOR)                  (INCLUDE IF NFIL>0)
   (EOF)                 (INCLUDE IF LAST CASE)
```

NOTATION	DESCRIPTION
NFIL	NUMBER OF FILES TO BE CATALOGED
LD(I)	=1 CATALOG (GEOMETRY FILE)
	=2 CATALOG (STATE FILE)
FILEI(I)	USER NAME FOR CATALOGED FILE

A.3 INPUT DATA FOR PROGRAM OEXEC (OEXEC DATA)

(OEXEC DATA) defines operations to be preformed for a structural or optimization analysis. The basic data consist of an operation number (ISTATE) and two qualifers IGOA and IGOB. These data are omitted for hardwired analyses if KRUN=2 OR 3 in the (GEOMETRY DATA). The operations performed are given under comments.

DATA FORMAT-

Numerical data are read in CDC free FORMAT. Zeros can not be replaced by blanks and all input values in a list must be given. File names are read in FORMAT A10. If more than one name is required, each name must be on a separate card. Labels of data sets must start in Column 1. (EOR) is an END-OF-RECORD mark which corresponds to a 789 punch in Column 1 on a card. (EOF) is an END-OF-FILE mark which corresponds to a 6789 punch in Column 1 on a card.

A.3.1 LIST AND DESCRIPTION OF (OEXEC DATA)

```
---------------------------------------------------------------------
   (ISTATE) (IGOA) (IGOB)
   (IFN(I),I=1,IGOA)                (INCLUDE IF ISTATE=7)
   (FILE)                           (INCLUDE IF IFN(I)>0)
   (EOR)                            (INCLUDE IF ISTATE=1,2,3,OR 7)
      REPEAT THE ABOVE SET UNTIL ALL OPERATIONS ARE DEFINED

NOTATION          DESCRIPTION

ISTATE          =1  EXECUTE ECHO
                    (THIS IS A RETURN TO ECHO FROM OEXEC)

ISTATE          =2  PERFORM STAGS BUCKLING ANALYSIS
IGOA            =0  SUPPRESS STAGS1 OUTPUT
                =1  PRINT STAGS1 OUTPUT
IGOB            =0  SUPPRESS STAGS2 OUTPUT
                =1  PRINT STAGS2 OUTPUT(EIGENVALUES AND MODES)

ISTATE          =3  PERFORM PASCO ANALYSIS
IGOA            =0  SUPPRESS PASCO OUTPUT
                =1  PRINT PASCO OUTPUT
IGOB            =N  NUMBER OF SUBSYNTHESIS CYCLES

ISTATE          =4  GENERATE CONSTRAINTS FOR OPTIMIZATION WITH
                    STAGS

ISTATE          =5  PERFORM OPTIMIZATION SUBSYNTHESIS
IGOA            =0  SET STARTING DECISION VARIABLES
                    TO PRESENT VALUES
                    XS(I)=X(I) I=1,NUMBER OF DECISION VARIABLES
                =1  RETAIN PRESENT STARTING DECISION VARIABLES

ISTATE          =6  DISPLAY STATE
IGOA            =0  DISPLAY ALL STATE VALUES
                =1  DISPLAY OPTIMIZATION STATE VALUES

ISTATE          =7  CATALOG FILES
IGOA            =N  NUMBER OF FILES TO BE CATALOGED (N<5)
IFN(I)          =1  CATALOG (GEOMETRY FILE)
                =2  CATALOG (DATA FILE)
                =3  CATALOG (STATE FILE)
                =4  CATALOG (EIGEN FILE)
FILE            FILE NAME TO BE CATALOGED FOR I=1,IGOA

ISTATE          =8  END PROBLEM

ISTATE          =9  GENERATE STAGS DATA FILE

IGOA=IGOB=0 UNLESS NOTED OTHERWISE
---------------------------------------------------------------------
```

COMMENTS ON OEXEC DATA

STAGS refers to programs STAGS, SFRITZ, and FRITZ. STAGS1 is a preprocessor and is used by STAGS and SFRITZ for data input. STAGS2, SFRITZ, and FRITZ perform computations for a structural analysis.
A typical (OEXEC DATA) for an optimization problem using STAGS (SFRITZ or FRITZ) is as follows:

```
    DATA                    OPERATION
(ISTATE)(IGOA)(IGOB)

6 0 0                       DISPLAY STATE
2 0 0                       PERFORM BUCKLING ANALYSIS
(EOR)
4 0 0                       GENERATE CONSTRAINTS
5 0 0                       OPTIMIZE( CYCLE 1 )
6 1 0                       DISPLAY STATE
2 0 0
(EOR)
4 0 0
5 0 0                       OPTIMIZE( CYCLE 2 )
6 1 0
REPEAT PREVIOUS 5 CARDS FOR EACH NEW CYCLE
7 2 0                       CATALOG 2 FILES
1 3                         CATALOG GEOMETRY AND STATE FILES
GFCAS1                      FILE NAME FOR (GEOMETRY FILE)
SFCAS1                      FILE NAME FOR (STATE FILE)
(EOR)
1 0 0                       RETURN TO ECHO
(EOR)
```

As seen, this data set can become large; therefore, in the interest of simplicity HARDWIRED options are provided which carry out the above operations but do not require user data.

Following is a listing of operations performed for HARDWIRED analyses using "STAGS" and PASCO.

```
          HARDWIRED STAGS ANALYSIS

    ISTATE=20,IGOA=1,IGOB=0
1.0       START
          NSTEP IS INITILIZED
          DISPLAY STATE
2.0       ANALYSIS PHASE
          IF KB=0,GO TO 3.0
2.1       PERFORM BUCKLING ANALYSIS
3.0       OPTIMIZATION PHASE
          IF KANAL=1,GO TO 4.0
          GENERATE CONSTRAINTS
          KS=0
3.1       KS=KS+1
          PERFORM OPTIMIZATION  SUBSYNTHESIS
```

```
          NSTEP=NSTEP+1
          IPRT=MOD(NSTEP,KDISPL)
          IF NSTEP=1 OR IPRT=0, DISPLAY STATE
          CONVERGENCE CHECK
          IF IDVV=1, GO TO 4.0
          ICYCLE=KSCYC-KS
          IF ICYCLE>0 AND NSTEP<KCYCL, GO TO 3.1
          IF NSTEP<KCYCL,GO TO 2.0
4.0       END PHASE
          IF KSAVE=0,GO TO 4.1
          CATALOG FILES
4.1       RETURN TO ECHO

          HARDWIRED ANALYSIS FOR PASCO

     ISTATE=19,IGOA=1,IGOB=0
          KCYCL=MAXIMUN NUMBER OF SUBSYNTHESIS CYCLES
          KDISPL= NUMBER OF CYCLES BETWEEN A CALL TO DISPLAY
1.0       START
          NSTEP IS INITILIZED
          CALL DISPLAY
2.0       ANALYSIS AND OPTIMIZATION PHASE
          IGOB=NUMBER OF SUBSYNTHESIS CYCLES
          IGOB=KDISPL
          IF KDISPL=0, IGOB=KCYCL
          IF KANAL=1, IGOB=0
2.1       PERFORM PASCO ANALYSIS
          NSTEP=NSTEP+IGOB
          IF KANAL=1, GO TO 4.0
          DISPLAY STATE
3.0       CONVERGENCE CHECK AND CYCLE CHECK
          ISTEP=KCYCL-NSTEP
          IF ISTEP<=0 OR IDCC=1, GO TO 4.0
          JSTEP=ISTEP-KDISPL
          IGOB=KDISPL
          IF JSTEP<0, IGOB=-JSTEP
          GO TO 2.1
4.0       END PHASE
          IF KSAVE=0, GO TO 4.1
          CATALOG FILES
4.1       RETURN TO ECHO
```

A.4 Input Requirements for (GEOMETRY DATA)

(GEOMETRY DATA) defines the problem to be analyzed and consists of up to 15 sets of data. The first card of each set must contain one of the following labels (left adjusted FORMAT(A10)): TITLE, CONTROL, LOAD, MATERIAL, BOUNDARY, PANEL, STIFFENER, THICKNESS, WALL, STAGS, CONSTRAINT, DECISION,OPTIMIZE, SAVE, and END. The last card of (GEOMETRY DATA) must be END.

DATA FORMAT-

Numerical data are read in CDC free FORMAT. Zeros can not be replaced by blanks and all input values in a list must be given. File names are read in FORMAT A10. If more than one name is required, each name must be on a separate card.
Labels of data sets must start in Column 1.
In the following, parameters included under the different labels are listed. Then follows an explanation of each of these parameters.

A.4.1 List of (GEOMETRY DATA)

```
TITLE
   (ANY ALPHAMERIC INFORMATION--ON ONE CARD)
CONTROL
   (KANAL) (KSANA) (KOPTM)
   (KRUN) (KCYCL) (KSCYC) (KPRINT) (KDISPL)
LOAD
   (NLOAD)
   ((NXX(I),NYY(I),NXY(I)),I=1,NLOAD)
MATERIAL
   (NMAT)
   ((E11(I),E22(I),E12(I),ANU1(I),RHO(I),TA1(I),TA2(I)),I=1,NMAT)
BOUNDARY
   (IBCN(I),I=1,4)
PANEL
   (KMT) (KPT) (NST) (NRG)
   (XL) (XT) (RA)
STIFFENER
   (NSW) (NSS) (NRS)
   (WS(J),J=1,NSW)                      (INCLUDE IF NSW>0)
   ((JWS(I),JAS(I),JCS(I)),I=1,NSS)     (INCLUDE IF NSS>0)
   ((JWR(I),JAR(I),JCR(I)),I=1,NRS)     (INCLUDE IF NRS>0)
THICKNESS
   (NDT) (NLOAD)
   ((T(J),ZET(J),(MAT(J,L),L=1,NLOAD)),J=1,NDT)
WALL
   (NLP) (NSS) (NRS)
   (NLI(I),I=1,NLP)                     (INCLUDE IF NLP>0)
   (LWALL(J,I),J=1,NLI(I))              (INCLUDE IF NLI(I)>0)
                                        (REPEAT NLP TIMES)
   (KWALP)
   (KWALS(K),K=1,NSS)                   (INCLUDE IF NSS>0)
   (KWALR(K),K=1,NRS)                   (INCLUDE IF NRS>0)
```

```
CONSTRAINT
   (NCTYP) (KCTYP(I),I=1,NCTYP)        (INCLUDE IF NCTYP>0)
   (PHI)                               (INCLUDE IF KCTYP(I)=1)
   ((EALLOW(J,I),I=1,5),J=1,NMAT)      (INCLUDE IF KCTYP(I)=2)
   ((SALLOW(J,I),I=1,5),J=1,NMAT)      (INCLUDE IF KCTYP(I)=3)
   ( ALLOWABLE TO BE INSERTED)         (ERROR IF KCTYP(I)=4)
   (FREQ(I),I=1,NLOAD)                 (INCLUDE IF KCTYP(I)=5)
DECISION
   (KWN(K),K=1,NSW)                    (INCLUDE IF NSW>0)
   (KTN(K),K=1,NDT)                    (INCLUDE IF NDT>0)
   (KAN(K),K=1,NDT)                    (INCLUDE IF NDT>0)
   (NTE(I),I=1,NLE)                    (INCLUDE IF NLE>0)
   (JV,FLE(JV,I)),K=1,NTE(I))          (INCLUDE IF NTE(I)>0)
                                       (REPEAT NLE TIMES)
   (XUB(I),I=1,NDV)                    (INCLUDE IF NDV>0)
   (XLB(I),I=1,NDV)                    (INCLUDE IF NDV>0)
OPTIMIZE
   (SMOVE) (SFACT)
   (IPRINT) (DELDV) (DDV)
SAVE
   (KSAVE)
   (LD(I),I=1,KSAVE)                   (INCLUDE IF KSAVE>0)
   (FILE)                              (INCLUDE IF LD(I)=1 OR 2)
STAGS
   (NKEY) (IKEY(I),I=1,NKEY)
   ((NRW(I),NCL(I)),I=1,NKEY)
   (NUMF(I),I=1,NKEY)                  (INCLUDE IF KSANA=-1 OR 0)
   ((MODE(J,I),KDIS(J,I),NHWX(J,I)     (INCLUDE IF KSANA=-1 OR 0)
    ,NHWY(J,I)),J=1,NUMF(I))           (REPEAT NKEY TIMES)
   (IPRD) (IPOLY) (ITEST)              (INCLUDE IF KSANA=-1)
 (END STAGS INPUT IF KANAL>0 AND KSANA>=0)
 (THE FOLLOWING DATA IS FOR A NONLINEAR ANALYSIS)
   (PNL(I),I=1,6)
   (NSYS) (NICS)
   ((ISYS(J),NLD(J),
   (P(L),LT(L),LD(L),LR(L),LC(L)),
    L=1,NLD(J)),J=1,NSYS)              (INCLUDE IF NSYS>0)
   (STN(I),I=1,3)                      (INCLUDE IF NICS>0)
   (IPDE)
   (KCTN)                              (INCLUDE IF IPDE>0)
   (NXL) (NYL) (NZSL) (NZRL)           (INCLUDE IF IPDE>0)
   (XXE(I),I=1,NXL)                    (INCLUDE IF IPDE>0)
   (YYE(I),I=1,NYL)                    (INCLUDE IF IPDE>0)
   (MATS(I),ANGS(I),ZSE(I),I=1,NZSL)   (INCLUDE IF IPDE>0
                                        AND NZSL>0)
   (MATR(I),ANGR(I),ZSE(I),I=1,NZRL)   (INCLUDE IF IPDE>0
                                        AND NZRL>0)
   (JRAND) (PMAX) (DELXY) (RANST)
END
```

A.4.2 Descritption of (GEOMETRY DATA)

INFORMATION ABOUT THE DATA SETS FOLLOWS

TITLE SET

THE TITLE SET CONSISTS OF THE FOLLOWING DATA:

TITLE
   (ANY ALPHAMERIC INFORMATION--ON ONE CARD)

COMMENTS ON TITLE SET

THIS SET ALLOWS THE USER TO IDENTIFY PARTICULAR CASES. THE "TITLE" IS READ ON ONE CARD THAT MAY CONTAIN ANY HOLLERITH TEXT. THE TEXT IS PRINTED AT THE BEGINNING OF THE "DISPLAY" OUTPUT (SEE OEXEC DATA). THIS SET CAN BE OMITTED IF THE USER DOES NOT NEED AN IDENTIFIER.

EXAMPLE OF TITLE SET INPUT:

```
TITLE
  EXAMPLE 1 CASE B  BLADE STIFFENED PANEL NX=-2000. PHI=.2 FRITZ
```

CONTROL PARAMETER SET

THE CONTROL SET CONSISTS OF THE FOLLOWING DATA:

```
CONTROL
   (KANAL) (KSANA) (KOPTM)
   (KRUN) (KCYCL) (KSCYC) (KPRINT) (KDISPL)
```

NOTATION	DESCRIPTION
KANAL	ANALYSIS TYPE
	=0 NONLINEAR STATIC STRESS ANALYSIS
	=1 BIFURCATION BUCKLING ANALYSIS
	=2 OPTIMIZE
KSANA	STRUCTURAL ANALYSIS METHOD
	=-1 FRITZ (FUNCTIONAL RALEIGH-RITZ)
	= 0 SFRITZ (STAGS FUNCTIONAL RALEIGH-RITZ)
	= 1 STAGS (VERSION STAGSC-1)
	= 2 PASCO
	= 3 PANEL (NOT OPERATIVE AT PRESENT)
KOPTM	OPTIMIZATION METHOD
	=1 CONMIN (VERSION 1972)
	=2 ALMIN (NOT OPERATIVE AT PRESINT)
KRUN	RUNSTREAM TYPE
	=0 ECHO DATA ON CARDS
	=1 ECHO DATA ON FILE DATE
	=2 HARDWIRED RUNSTREAM FOR OEXEC (ECHO DATA) IS ON CARDS
	=3 HARDWIRED RUNSTREAM FOR OEXEC (ECHO DATA IS ON FILE DATE
KCYCL	MAXIMUM NUMBER OF SUBSYNTHESES CYCLES FOR

```
                    OPTIMIZATION-REQUIRED IF KRUN=2 OR 3
                  =0  STRUCTURAL ANALYSIS
                  =M  RUN FOR M CYCLES
KSCYC               NUMBER OF SUBSYNTHESIS CYCLES BETWEEN
                    COMPUTING NEW CONSTRAINTS (FOR STAGS ONLY)
KPRINT              PRINT OUTPUT OPTIONS
                  =0  PRINT OUTPUT SUPPRESSED FOR STRUCTURAL
                      ANALYSIS
                  =1  PRINT PASCO OR STAGS2 OUTPUT
                  =2  PRINT STAGS1 AND STAGS2 OUTPUT
KDISPL              DISPLAY STATE
                  =0  DISPLAY IS SUPPRESSED
                  =N  DISPLAY STATE AFTER EACH N CYCLES

COMMENTS ON CONTROL SET-
```

LOAD SET

THE LOAD SET CONSISTS OF THE FOLLOWING DATA:

```
LOAD
   (NLOAD)
   ((NXX(I),NYY(I),NXY(I)),I=1,NLOAD)
```

NOTATION	DESCRIPTION
NLOAD	NUMBER OF LOAD SETS
NXX(I),NYY(I)	APPLIED INPLANE LOADS FOR LOAD SET I
NXY(I)	SEE FIGURE 1 FOR POSITIVE DIRECTIONS.

COMMENTS ON LOAD SET-

MATERIAL SET

THE MATERIAL SET CONSISTS OF THE FOLLOWING DATA:

```
MATERIAL
   (NMAT)
   ((E11(I),E22(I),E12(I),ANU1(I),RHO(I),TA1(I),TA2(I)),I=1,NMAT)
```

NOTATION	DESCRIPTION
NMAT	NUMBER OF DISTINCT MATERIALS
E11(I),E22(I)	YOUNG'S MODULUS IN DIRECTIONS 1 AND 2 FOR MATERIAL NUMBER(I)
E12(I)	SHEAR MODULUS FOR MATERIAL NUMBER(I)
ANU1(I)	POISSON'S RATIO FOR MATERIAL NUMBER(I)
RHO(I)	DENSITY OF MATERIAL NUMBER(I)
TA1(I),TA2(I)	COEFFICIENT OF THERMAL EXPANSION IN DIRECTIONS 1 AND 2 FOR MATERIAL NUMBER (I)

COMMENTS ON MATERIAL SET-

SIJ=STRESS IN IJ DIRECTION I=1,2 J=1,2
EPIJ=STRAIN IN IJ DIRECTION I=1,2 J=1,2
TAJ(I)= COEFFICIENT OF THERMAL EXPANION IN DIRECTION J
DT= CHANGE IN TEMPERATURE FROM REFERENCE TEMPERATURE

$$\begin{vmatrix} S11 \\ S22 \\ S12 \end{vmatrix} = C \begin{vmatrix} EP11-TA1(I)*DT \\ EP22-TA2(I)*DT \\ EP12 \end{vmatrix}$$

$$C = \begin{vmatrix} C11 & C22 & 0. \\ C21 & C22 & 0. \\ 0. & 0. & C33 \end{vmatrix}$$

IN WHICH
C11=E11(I)/CD ; C22=E22(I)/CD ;C21=C12 ;
C12=ANU1(I)*E22(I)/CD ; C21=ANU2(I)*E11(I)/CD
CD=1.-ANU1(I)*ANU2(I)
ANU2(I)=ANU1(I)*E22(I)/E11(I)

BOUNDARY CONDITION SET

THE BOUNDARY SET CONSISTS OF THE FOLLOWING DATA:

BOUNDARY
(IBCN(I),I=1,4)

NOTATION	DESCRIPTION
IBCN(I)	BOUNDARY CONDITION ALONG EDGE I
	=1 SIMPLE SUPPORT (ANTIMETRIC)
	=2 CLAMPED
	=3 FREE
	=4 SYMMETRIC

COMMENTS ON BOUNDARY SET-

SEE FIGURE 2 FOR DEFINITION OF BOUNDARY EDGE NUMBERING.

PANEL GEOMETRY SET

THE PANEL SET CONSISTS OF THE FOLLOWING DATA:

PANEL
(KMT) (KPT) (NST) (NRG)
(XL) (XT) (RA)

NOTATION	DESCRIPTION

KMT	STIFFENER MODEL TYPE IF KMT=1,2, OR 3 ALL STIFFENERS ARE OPEN CROSS-SECTIONS IF KMT>3 STRINGERS ARE CLOSED AND RINGS ARE OPEN CROSS-SECTIONS =1,4 NO STIFFENERS ON EDGES =2,5 STIFFENERS ON EDGES HAVE ONE HALF STIFFNESS AND DENSITY AS THOSE BETWEEN EDGES =3,6 STIFFENERS ON EDGES HAVE SAME PROPERTIES AS THOSE BETWEEN EDGES
KPT	PANEL TYPE =1 FLAT PANEL =2 CYLINDRICAL PANEL
NST	NUMBER OF STRINGERS BETWEEN PANEL EDGES
NRG	NUMBER OF RINGS BETWEEN PANEL EDGES
XL	PANEL LENGTH
XT	PANEL WIDTH
RA	RADIUS OF CYLINDRICAL PANEL

COMMENTS ON PANEL SET-

STIFFENER DEFINITION SET

THE STIFFENER SET CONSISTS OF THE FOLLOWING DATA:

STIFFENER

(NSW) (NSS) (NRS)	
(WS(J),J=1,NSW)	(INCLUDE IF NSW>0)
((JWS(I),JAS(I),JCS(I)),I=1,NSS)	(INCLUDE IF NSS>0)
((JWR(I),JAR(I),JCR(I)),I=1,NRS)	(INCLUDE IF NRS>0)

NOTATION	DESCRIPTION
NSW	NUMBER OF DISTINCT STIFFENER SEGMENT WIDTHS
NSS	NUMBER OF SEGMENTS IN STRINGER
NRS	NUMBER OF SEGMENTS IN RING
WS(J)	WIDTH OF DISTINCT STIFFENER SEGMENT NUMBER(J)
JWS(I),JWR(I)	WIDTH NUMBER(J) OF SEGMENT(I) FOR STRINGER(JWS) OR RING(JWR)
JAS(I),JAR(I)	ORIENTATION ANGLE(DEGREES) OF SEGMENT(I) FOR STRINGER(JAS) OR RING(JAR)
JCS(I),JCR(I)	CONNECTIVITY OF SEGMENT(I) FOR STRINGER(JCS) OR RING(JCR)

COMMENTS ON STIFFENER SET-

A STIFFENER IS COMPOSED OF (NSS FOR STRINGERS,NRS FOR RINGS) FLAT SEGMENTS EACH OF WHICH CAN BE ROTATED BY AN ANGLE (JAS,JAR) AND JOINED TOGETHER IN A PRESCRIBED MANNER. THE WIDTH OF EACH SEGMENT CAN BE A DESIGN VARIABLE; HOWEVER, IF MORE THAN ONE SEGMENT HAS THE SAME WIDTH ONLY THE DISTINCT WIDTHS (WS(J)) NEED BE SPECIFIED.

A STIFFENER SEGMENT WIDTH NUMBER J IS DEFINED BY THE ORDER IN WHICH THE WIDTHS (WS(J)) ARE READ, FOR EXAMPLE, IN THE ARRAY OF 2 WIDTHS (NSW=2)

(WS(J),J=1,2) = (1.0,0.5)

WIDTH 1.0 HAS WIDTH NUMBER 1 AND WIDTH 0.5 HAS WIDTH NUMBER 2.

THE ORIENTATION ANGLE (JAS OR JAR) DEFINES THE ANGLE A SEGMENT IS ROTATED FROM THE POSITIVE Z AXIS TO THE X OR Y AXIS. EDGE 1 IS INITIALLY AT THE COORDINATE LOCATION X,Y,Z=(0,0,0) AND EDGE 2 IS A DISTANCE WS FROM THE ORIGIN. AN ANGLE 0 DENOTES A SEGMENT EXTENDING ALONG THE POSITIVE Z AXIS, THUS THE COORDINATES OF EDGES 1 AND 2 ARE (0,0,0); (0,0,WS). LIKEWISE AN ANGLE OF 180 HAS COORDINATES OF EDGES 1 AND 2 AS (0,0,0); (0,0,-WS). THE ANGLES 90. AND -90. PRODUCE SEGMENTS PARALLEL TO THE X OR Y COORDINATES DEPENDING WHETHER THEY ARE RINGS OR STRINGERS.

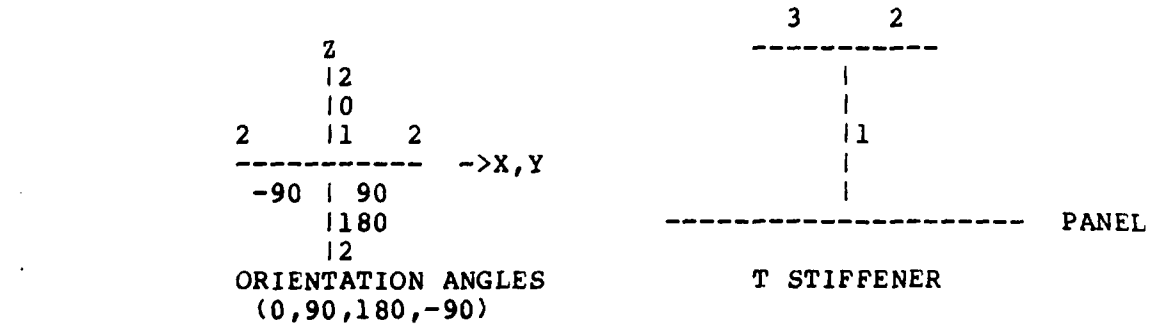
THE CONNECTIVITY (JCS,JCR) IS USED TO JOIN THE ROTATED SEGMENTS TOGETHER AND IS THE SEGMENT NUMBER TO WHICH EDGE 1 ATTACHES TO EDGE 2 OF A PREVIOUS SEGMENT. THE PANEL IS SEGMENT NUMBER 0, AND THE SEGMENT NUMBER IS DEFINED BY THE ORDER IN WHICH JWS,JAS,JCS ARE READ.

EXAMPLE- TO FORM A T STRINGER WITH TWO DISTINCT WIDTHS THE INPUT DATA IS AS FOLLOWS:

DATA	NOTATION
STIFFENER	
2,3,0	(NSW),(NSS),(NRS)
1.0,0.5	WS(1),WS(2)
1,0.,0	(JWS(1)),(JAS(1)),(JCS(1))
2,90.,1	(JWS(2)),(JAS(2)),(JCS(2))
2,-90.,1	(JWS(3)),(JAS(3)),(JCS(3))

THE , MAY BE REPLACED BY A BLANK.
THE INPUT COULD ALSO BE AS FOLLOWS

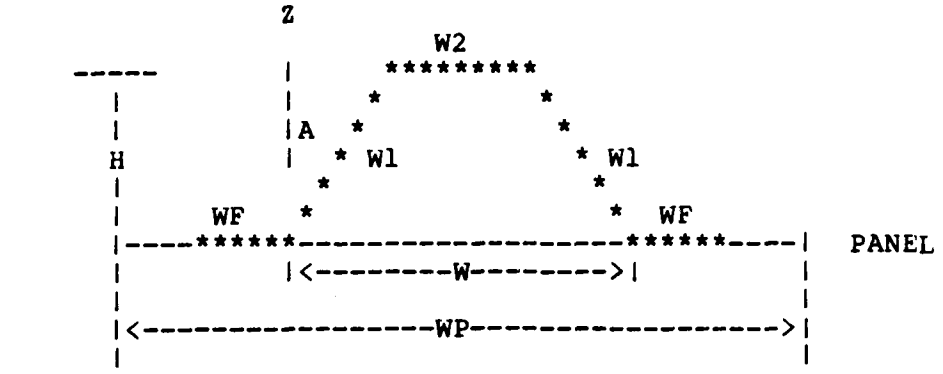
```
STIFFENER
2 0 3 1. .5 1 0 0 2 90. 1 2 -90. 1
```



HAT STRINGER

WHEN KMT>3 THE HAT STIFFENER SHOWN CAN BE MODELED IN PASCO. WP

IS THE WIDTH BETWEEN REPEATING STRINGERS (WP=XT/NST) AND A IS A FIXED ANGLE BETWEEN THE Z AXIS AND THE SEGMENT W1.



HAT STIFFENER

A HAT STRINGER IS DEFINED BY 5 DISTINCT WIDTHS
(WS(I),I=1,5)=(W,H,WF,W1,W2)
AND 5 SEGMENTS WITH THE FOLLOWING WIDTHS
(WF,W1,W2,W1,WF)
THE VALUES OF JWS,JAS,JCS ARE

```
3 0 0
4 A 1
5 0 2
4 (180-A) 3
3 0 4
```

W,H,WF CAN BE DECISION VARIABLES AND W1,W2 ARE DEPENDENT VARIABLES. THE ANGLE A AND PANEL WIDTH WP ARE FIXED.
TWO LINKING EQUATIONS MUST BE GIVEN FOR W1 AND W2

```
H - COS(A) * W1 = 0
-W + 2.*TAN(A) * H + W2 = 0
```

THICKNESS LAYERING SET

THE THICKNESS SET CONSISTS OF THE FOLLOWING DATA:

THICKNESS
(NDT) (NLOAD)
((T(J),ZET(J),(MAT(J,L),L=1,NLOAD)),J=1,NDT)

NOTATION	DESCRIPTION
NDT	NUMBER OF DISTINCT LAYERS A DISTINCT LAYER HAS THE SAME THICKNESS,ANGLE AND MATERIAL
T(J)	THICKNESS OF DISTINCT LAYER NUMBER(J)
ZET(J)	MATERIAL ORIENTATION ANGLE OF LAYER NUMBER(J)
MAT(J,L)	MATERIAL NUMBER(I) OF DISTINCT LAYER NUMBER(J) FOR LOAD SET(L)

COMMENTS ON THICKNESS SET-

A (THICKNESS/MATERIAL) LAYER IS DEFINED BY A THICKNESS, MATERIAL ORIENTATION ANGLE AND MATERIAL NUMBERS(CORRESPONDING TO I IN SET MATERIAL) FOR EACH LOAD SET. A DISTINCT LAYER IS ONE IN WHICH ALL OF THE QUANTITIES ARE EQUAL. A LAYER NUMBER IS DEFINED BY THE ORDER IN WHICH T,ZET, MAT ARE READ. T AND ZET ARE DESIGN VARIABLES AND CAN BE FIXED, INDEPENDENT, OR DEPENDENT VARIABLES. EXAMPLE- HERE THERE ARE 4 DISTINCT LAYERS, ONE MATERIAL AND 1 LOAD SET:

DATA	NOTATION
THICKNESS	
4,1	NDT,NLOAD
5.-3,0.,1	T(1),ZET(1),MAT(1,1)
5.-3,45.,1	T(2),ZET(2),MAT(2,1)
5.-3,-45.,1	T(3),ZET(3),MAT(3,1)
5.-3,90.,11	T(4),ZET(4),MAT(4,1)

THE THICKNESS OF LAYERS 2,3 AND 4 CAN BE LINKED TO THE THICKNESS OF LAYER 1 BY THE 3 EQUATIONS

$$T(1) - T(2) = 0$$
$$T(1) - T(3) = 0$$
$$T(1) - T(4) = 0$$

RESTRICTIONS NDT<21 , NLOAD<5.

WALL LAYERING SET

THE WALL SET CONSISTS OF THE FOLLOWING DATA:

WALL	
(NLP) (NSS) (NRS)	
(NLI(I),I=1,NLP)	(INCLUDE IF NLP>0)
(LWALL(J,I),J=1,NLI(I))	(INCLUDE IF NLI(I)>0) (REPEAT NLP TIMES)
(KWALP)	
(KWALS(K),K=1,NSS)	(INCLUDE IF NSS>0)
(KWALR(K),K=1,NRS)	(INCLUDE IF NRS>0)

NOTATION	DESCRIPTION
NLP	NUMBER OF DISTINCT WALL LAYERINGS
NLI(I)	NUMBER OF LAYERS IN WALL NUMBER(I)
LWALL(J,I)	LAYER NUMBER(K) OF LAYER(J) FOR WALL NUMBER(I)
KWALP	WALL NUMBER(I) OF PANEL
KWALS(K),KWALR(K)	WALL NUMBER(I) OF SEGMENT(K) FOR STRINGER(KWALS) OR RING(KWALR)

COMMENTS ON WALL SET-

DATA IN THIS SET DEFINES WALL LAYERINGS AND THE LAYERING ASSOCIATED WITH THE PANEL AND STIFFENER SEGMENTS. A DISTINCT WALL LAYERING IS DEFINED BY THE NUMBER OF LAYERS IN THE WALL (NLI(I)) AND THE LAYERING ORDER (LWALL(J,I)). THE INDEX I DEFINES THE WALL NUMBER AND THE STACKING ORDER OF LAYERS FROM THE INNER SURFACE. IN A PASCO ANALYSIS, THE LAYERING MUST BE SYMMETRIC ABOUT THE WALL MIDDLE SURFACE.

THE QUANTIES KWALP,KWALS, KWALR ARE THE WALL NUMBER FOR THE PANEL STRINGER AND RING SEGMENTS.
EXAMPLE- TWO DISTINCT LAYERINGS ARE GIVEN FOR THE T STRINGERS AND 4 LAYERS PREVIOUSLY DEFINED

DATA	NOTATION
WALL	
2,3,0	NLP,NSS,NRS
14,2	NLI(1),NLI(2)
1,2,3,4,3,2,1,1,2,2,4,3,2,1	(LWALL(J,1),J=1,14)
1,1	(LWALL(J,2),J=1,2)
1	KWALP
2,2,2	KWALS(K),K=1,3)

THIS DATA IMPLIES THAT THE PANEL HAS 14 LAYERS (0/+-45/90/-+45/0)S AND ALL STRINGER SEGMENTS HAVE 2 LAYERS (0)S.

CONSTRAINT SET

THE CONSTRAINT SET CONSISTS OF THE FOLLOWING DATA:

CONSTRAINT	
(NCTYP) (KCTYP(I),I=1,NCTYP)	(INCLUDE IF NCTYP>0)
(PHI)	(INCLUDE IF KCTYP(I)=1)
((EALLOW(J,I),I=1,5),J=1,NMAT)	(INCLUDE IF KCTYP(I)=2)
((SALLOW(J,I),I=1,5),J=1,NMAT)	(INCLUDE IF KCTYP(I)=3)
(ALLOWABLE TO BE INSERTED)	(ERROR IF KCTYP(I)=4)
(FREQ(I),I=1,NLOAD)	(INCLUDE IF KCTYP(I)=5)

NOTATION	DESCRIPTION
NCTYP	NUMBER OF CONSTRAINT TYPES
KCTYP(I)	CONSTRAINT TYPE
	=1 BUCKLING CONSTRAINT
	=2 STRAIN CONSTRAINT
	=3 STRESS CONSTRAINT
	=4 (NOT OPERATIVE)
	=5 FREQUENCY CONSTRAINT
PHI	BUCKLING MODE SEPARATION PARAMETER
EALLOW(J,I)	ALLOWABLE STRAINS(I) FOR MATERIAL NUMBER(J)
SALLOW(J,I)	ALLOWABLE STRESSES(I) FOR MATERIAL NUMBER(J)
FREQ(I)	ALLOWABLE FREQUENCY FOR LOAD SET(I)

COMMENTS ON CONSTRAINT SET-

THREE CONSTRAINT TYPES ARE PRESENTLY OPERATIONAL
1 BUCKLING
2 MAXIMUM STRAIN
3 MAXIMUM STRESS.
THE DATA REQUIRED ARE THE MODE SEPARATION PARAMETER PHI AND ALLOWABLE VALUES FOR STRAIN AND STRESS.
THE PARAMETER PHI DEFINES THE RATIO BETWEEN LOCAL AND GENERAL INSTABILITY. A VALUE OF PHI<1 IMPLIES THAT LOCAL INSTABILITY WILL OCCUR AT A LOAD LESS THAN THE GIVEN LOAD LEVEL. WHEN PHI=1 BOTH GENERAL AND LOCAL INSTABILITY MAY OCCUR SIMULTANEOUSLY AT

THE GIVEN LOAD LEVEL.
THE 5 STRAIN ALLOWABLES EALLOW(J,I),I=1,5 FOR MATERIAL J ARE IN THE ORDER COMPRESSION, TENSION IN THE MATERIAL 1 DIRECTION, COMPRESSION, TENSION IN THE 2 DIRECTION AND SHEAR.
THE 5 STRESS ALLOWABLES HAVE A SIMILAR ORDERING. TENSION IS POSITIVE AND COMPRESSION IS NEGATIVE. THE ALLOWABLE VALUES SHOULD BE SUCH AS TO RESTRICT THE ANALYSIS TO AN ELASTIC STATE.
EXAMPLE- THIS IS AN OPTIMIZATION PROBLEM (KANAL=2) WITH ONE MATERIAL, AND BUCKLING AND STRAIN CONSTRAINTS.

```
   DATA                NOTATION
CONSTRAINT
2,1,2                  NCTYP,(KCTYP(I),I=1,NCTYP)
1.                     PHI
-10.-3,9.-3,-14.-3,7.-3,20.-3
                       (EALLOW(1,I),I=1,5)
```

DECISION VARIABLE SET

THE DECISION SET CONSISTS OF THE FOLLOWING DATA:

```
DECISION
   (KWN(K),K=1,NSW)                    (INCLUDE IF NSW>0)
   (KTN(K),K=1,NDT)                    (INCLUDE IF NDT>0)
   (KAN(K),K=1,NDT)                    (INCLUDE IF NDT>0)
   (NTE(I),I=1,NLE)                    (INCLUDE IF NLE>0)
   (JV,FLE(JV,I)),K=1,NTE(I))          (INCLUDE IF NTE(I)>0)
                                       (REPEAT NLE TIMES)
   (XUB(I),I=1,NDV)                    (INCLUDE IF NDV>0)
   (XLB(I),I=1,NDV)                    (INCLUDE IF NDV>0)
```

NOTATION	DESCRIPTION
KWN(K),KTN(K), KAN(K)	STATUS OF VARIABLES WIDTH(WS(K)),THICKNESS(T(K)) AND ANGLE(ZET(K)) =0 FIXED VARIABLE =1 DECISION,MASTER,INDEPENDENT VARIABLE =2 LINKED,SLAVE,DEPENDENT VARIABLE
NDV	NUMBER OF DECISION VARIABLES
NLE	NUMBER OF LINKING EQUATIONS
NTE(I)	NUMBER OF TERMS IN LINKING EQUATION(I)
JV	VARIABLE NUMBER
FLE(JV,I)	COEFFICIENT MULTIPLIED BY VARIABLE JV IN LINKING EQUATION(I)
XUB(I)	UPPER BOUND OF DECISION VARIABLE(I)
XLB(I)	LOWER BOUND OF DECISION VARIABLE(I)

COMMENTS ON DECISION SET-

THIS SET IS INCLUDED IF KANAL=2 OR IF VARIABLES ARE LINKED. AS NOTED PREVIOUSLY WS,T, AND ZET ARE DESIGN VARIABLES AND EACH CAN BE CLASSED AS A FIXED, DECISION OR LINKED VARIABLE. DATA IN THIS SET DEFINES THE STATUS OF THE DESIGN VARIABLES, LINKING EQUATIONS AND UPPER AND LOWER BOUNDS OF THE DECISION VARIABLES. THE

QUANTITIES KWN,KTN,KAN DEFINE THE GROUP IN WHICH THE STIFFENER WIDTHS (WS), THICKNESSES (T), AND MATERIAL ORIENTATION ANGLES (ZET) ARE IN BY ASSIGNING THE NUMBER 0,1, OR 2 TO EACH OF THE DESIGN VARIABLES (0-FIXED,1-DECISION, 2-LINKED).
THE VECTOR IVN IS DEFINED AS

(IVN(I),I=1,M) = ((KWN(K),K=1,NSW),(KTN(K),K=1,NDT), (ZET(K),K=1,NDT))

M=NSW + 2*NDT

THE SUM OF ALL VALUES IN IVN WHICH ARE 1 EQUALS THE NUMBER OF DECISION VARIABLES (NDV), AND THE SUM OF ALL VALUES WHICH ARE 2 EQUALS THE NUMBER OF LINKED VARIABLES (NLE). NDV AND NLE ARE COMPUTED IN ECHO, THUS ARE NOT REQUIRED INPUT PARAMETERS.
LINKING EQUATIONS
IF NLE>0 THEN NLE LINEAR EQUATIONS IN TERMS OF THE DESIGN VARIABLES MUST BE DEFINED. THE ARRAY DV(I) INCLUDES AA DESIGN VARIABLES AS

(DV(I),I=1,M) = ((WS(K),K=1,NSW),(T(K),K=1,NDT), (ZET(K),K=1,NDT))

THE INDEX I IN THE ARRAY DV(I) IS THE DESIGN VARIABLE NUMBER.
UPPER AND LOWER BOUNDS
THE SUBSET OF DV WHICH ARE DECISION VARIABLES ARE IN THE ARRAY X(I) AND THE INDEX I IS THE DECISION VARIABLE NUMBER. UPPER AND AND LOWER BOUNDS XUB(I),XLB(I) ARE ONLY GIVEN FOR THE DECISION VARIABLES.

OPTIMIZATION SET

THE OPTIMIZE SET CONSISTS OF THE FOLLOWING DATA:

OPTIMIZE
(SMOVE) (SFACT)
(IPRINT) (DELDV) (DDV)

NOTATION	DESCRIPTION
SMOVE,SFACTOR	PARAMETERS USED TO DETERMINE THE RATE AT WHICH BOUNDS OF THE DECISION VARIABLES ARE DECREASED IN EACH SUBSYNTHESIS CYCLE
IPRINT	PRINT CONTROL FOR OPTIMIZER
=0	NO PRINTED OUTPUT FROM OPTIMIZER
=1	PRINT INITIAL AND FINAL FUNCTION INFORMATION
>1	INTERMEDIATE DATA PRINTED
DELDV	PARAMETER USED TO COMPUTE DERIVATIVE OF DECISION VARIABLES
DDV	OVERALL CONVERGENCE CRITERION

COMMENTS ON OPTIMIZE SET-

SAVE FILE SET

THE SAVE SET CONSISTS OF THE FOLLOWING DATA:

SAVE

```
   (KSAVE)
   (LD(I),I=1,KSAVE)                    (INCLUDE IF KSAVE>0)
   (FILE)                               (INCLUDE IF LD(I)=1 OR 2)

NOTATION          DESCRIPTION

KSAVE               NUMBER OF FILES TO BE CATALOGED
LD(I)               FILE TO BE CATALOGED
                  =1  CATALOG (GEOMETRY FILE)
                  =2  CATALOG (STATE FILE)
FILE                USERS NAME FOR FILE

COMMENTS ON SAVE SET-

-------------------------------------------------------------------
STAGS INPUT SET

THE STAGS SET CONSISTS OF THE FOLLOWING DATA:

STAGS
   (NKEY) (IKEY(I),I=1,NKEY)
   ((NRW(I),NCL(I)),I=1,NKEY)
   (NUMF(I),I=1,NKEY)                   (INCLUDE IF KSANA=-1 OR 0)
   ((MODE(J,I),KDIS(J,I),NHWX(J,I)      (INCLUDE IF KSANA=-1 OR 0)
    ,NHWY(J,I)),J=1,NUMF(I))            (REPEAT NKEY TIMES)
   (IPRD) (IPOLY) (ITEST)               (INCLUDE IF KSANA=-1)
 (END STAGS INPUT IF KANAL>0 AND KSANA>=0)
 (THE FOLLOWING DATA IS FOR A NONLINEAR ANALYSIS)
   (PNL(I),I=1,6)
   (NSYS) (NICS)
   ((ISYS(J),NLD(J),
   (P(L),LT(L),LD(L),LR(L),LC(L)),
    L=1,NLD(J)),J=1,NSYS)               (INCLUDE IF NSYS>0)
   (STN(I),I=1,3)                       (INCLUDE IF NICS>0)
   (IPDE)
   (KCTN)                               (INCLUDE IF IPDE>0)
   (NXL) (NYL) (NZSL) (NZRL)            (INCLUDE IF IPDE>0)
   (XXE(I),I=1,NXL)                     (INCLUDE IF IPDE>0)
   (YYE(I),I=1,NYL)                     (INCLUDE IF IPDE>0)
   (MATS(I),ANGS(I),ZSE(I),I=1,NZSL)    (INCLUDE IF IPDE>0
                                         AND NZSL>0)
   (MATR(I),ANGR(I),ZSE(I),I=1,NZRL)    (INCLUDE IF IPDE>0
                                         AND NZRL>0)
   (JRAND) (PMAX) (DELXY) (RANST)

NOTATION          DESCRIPTION

NKEY                NUMBER OF STRUCTURAL MODELS
IKEY(I)             MODEL TYPE
                  =0  PANEL WITH DISCRETE STIFFENERS
                  =1  PANEL WITH SMEARED STIFFENERS
                  =2  PANEL BETWEEN STIFFENERS,STIFFENERS ON EDGES
                  =3  PANEL BETWEEN STIFFENERS,NO STIFFENERS
                  =4  STRINGER ALONE, FLANGES ARE DISCRETE
                  =5  RING ALONE, FLANGES ARE DISCRETE
```

```
NRW(I),NCL(I)       NUMBER OF ROWS AND COLUMNS FOR MODEL I
NUMF(I)             NUMBER OF MODAL FUNCTIONS FOR MODEL I
MODE(J,I)           MODE NUMBER  FOR MODE J ,MODEL I
KDIS(J,I)           DISPLACEMENT TYPE FOR MODE J,MODEL I
                  =0  U,V COMPONENTS DETERMINED FROM EQUILIBRIUM
                  =1  U DISPLACEMENT, X DIRECTION
                  =2  V DISPLACEMENT, Y DIRECTION
                  =3  W DISPLACEMENT, Z DIRECTION
NHWX(J,I)           NUMBER OF HALF WAVES IN X DIRECTION
                    (MODE J, MODEL I)
NHWY(J,I)           NUMBER OF HALF WAVES IN Y DIRECION
                    (MODE J, MODEL I)
IPRD                PRINT DISPLACEMENTS EVERY IPRD STEPS
IPLOY               POLYNOMINAL APPROXIMATION IN FRITZ
                  =2  FOR BIFURCATION BUCKLING ANALYSIS
                  =4  FOR NONLINEAR ANALYSIS
ITEST               PRINT OUT INTERMEDIATE DATA IF ITEST > 0
PNL(I)              LOAD MULTIPLIER SET
PNL(1),PNL(2),      STARTING LOAD FACTOR, LOAD FACTOR INCREMENT,
PNL(3)              MAXIMUM LOAD FACTOR FOR LOAD SYSTEM A
PNL(4),PNL(5),      STARTING LOAD FACTOR, LOAD FACTOR INCREMENT,
PNL(6)              MAXIMUM LOAD FACTOR FOR LOAD SYSTEM B
NSYS                NUMBER OF LOAD SYSTEMS TO BE DEFINED
NICS                LOADING BY UNIFORM STRAIN FIELD
ISYS(J)             LOADS APPLY TO LOAD SYSTEM A OR B
                    IF ISYS=1 OR 2
NLD(J)              NUMBER OF LOADS TO BE DEFINED
P(L)                VALUE OF BASE LOAD
LT(L)               LOAD TYPE
                 =-1  DISPLACEMENT
                 = 1  POINT FORCE
                 = 2  LINE LOAD ALONG ROW
                 = 3  LINE LOAD ALONG COLUMN
                 = 4  SURFACE TRACTION
LD(L)               LOAD DIRECTION
                 = 1 U
                 = 2 V
                 = 3 W
LR(L),LC(L)         ROW AND COLUMN AT WHICH P(L) IS APPLIED
STN(I)              VALUES OF BASE STRAIN
STN(1),STN(2)       STRAIN IN X AND Y DIRECTION (EPXX),(EPYY)
STN(3)              SHEAR STRAIN (EPXY)
IPDE                CHECK FAILURE CRITERIA EVERY IPDE STEPS
KCTN                FAILURE CRITERIA TYPE
                 = 1  MAXIMUM STRAIN
                 = 2  EFFECTIVE STRESS(VON MISES FOR
                        ISOTROPIC MATEIALS)
NXL,NYL             NUMBER OF X AND Y LOCATIONS AT WHICH
                    FAILURE CRITERIA IS CHECKED
NZSL,NZRL           NUMBER OF Z LOCATIONS ON STRINGERS AND RINGS
                    AT WHICH FAILURE CRITERIA IS CHECKED
XXE(I)              X-LOCATIONS
YYE(I)              Y-LOCATIONS
MATS(I),MATR(I)     MATERIAL NUMBERS FOR STRINGER AND RING
ANGS(I),ANGR(I)     MATERIAL ORIENTATION ANGLE FOR STRINGER
```

	AND RING
ZSE(I),ZRE(I)	Z-LOCATION FOR STRINGER AND RING
JRAND	NUMBER OF RANDOM LOAD CASES
PMAX	MAXIMUM VALUE OF RANDOM NUMBERS
DELXY	PARAMETER NOT USED AT PRESENT SET TO 0.
RANST	STARTING NUMBER FOR RANDOM NUMBER SEQUENCE (IF RANST=0., PROGRAM SELECTS A RANDOM NUMBER)

COMMENTS ON STAGS SET-

THIS SET IS REQUIRED IF THE STRUCTURAL ANALYZER IS FRITZ, SFRITZ, OR STAGS (KANAL=1,0, OR -1 IN CONTROL SET) AND THIS IS A BUCKLING ANALYSIS (KSANA=1), OPTIMIZATION WITH BUCKLING CONSTRAINTS (KSANA=2 AND KCTYP(I)=1, IN CONSTRAINT SET), OR A NONLINEAR ANALYSIS (KSANA=0). NOTE THAT FOR OPTIMIZATION WITH ONLY STRESS OR STRAIN CONSTRAINTS THIS SET IS NOT REQUIRED.

THE BOUNDARY CONDITIONS GIVEN UNDER THE BOUNDARY SET APPLY TO MODELS 0 AND 1. IN A STAGS ANALYSIS THE BOUNDARY CONDITIONS CAN BE IN ANY COMBINATION OF THOSE SPECIFIED UNDER THE BOUNDARY SET. AT PRESENT THE USER DEFINED MODAL FUNCTIONS FOR A FRITZ OR SFRITZ ANALYSIS APPLY ONLY TO SIMPLE SUPPORT AND SYMMETRY CONDITIONS ON OPPOSITE EDGES OF THE PANEL.

FOR A NONLINEAR ANALYSIS THE USER MUST SELECT MODEL 0 AND THE STRUCTURAL ANALYZER MUST BE STAGS OR FRITZ. IF THE ANALYZER IS STAGS THEN THE ANALYSIS IS TO BE PERFORMED BY PROGRAM RRSYS. WITH ANALYZER FRITZ THE ANALYSIS CAN BE PERFORMED IN ECHO.

FOR AN OPTIMIZATION PROBLEM WITH BUCKLING CONSTRAINTS THE USER MUST SELECT MODELS WHICH GENERATE BUCKLING MODES THAT DESCRIBE GENERAL AND LOCAL BUCKLING IF THE PANEL IS STIFFENED. FOR AN UNSTIFFENED PANEL MODELS 0 OR 1 CAN BE USED. ALSO MODEL 3 CAN BE USED IF THE PANEL IS SIMPLY SUPPORTED ALONG ALL EDGES. WITH STAGS AS THE ANALYZER, MODEL 1 (PANEL WITH SMEARED STIFFENERS) MUST BE USED TO DESCRIBE GENERAL BUCKLING.

DISCRETIZATION- A SUFFICIENT MUMBER OF ROWS AND COLUMNS MUST BE PRESCRIBED IN ORDER TO DESCRIBE THE BUCKLE MODES. THIS CAN BE ACCOMPLISHED BY A CONVERGENCE STUDY.

END SET
THE LAST DATA STATEMENT OF (GEOMETRY DATA) IS THE LABEL END.

APPENDIX B

PROGRAM STORE

Program STORE translates PANDA output data to a (GEOMETRY FILE) which can be read in program ECHO. STORE can be executed interactively or in a batch mode. See Appendix C for procedure file ECHOPE to execute STORE in a batch mode. Input to STORE are responses to questions or statements. A listing of these questions and the possible responses by the user, and a sample data set follows.

Question Number	Question Response(input by user)
1	PLEASE INDICATE WHETHER THIS IS TO BE A STRUCTURAL ANALYSIS ONLY (WITHOUT ANY OPTIMIZATION) OR IS IT TO BE AN OPTIMIZATION ANALYSIS. IS THIS TO BE AN OPTIMIZATION ANALYSIS
R	YES OR NO
2	YOU CAN DO THE STRUCTURAL ANALYSIS WITH FRITZ,SFRITZ, STAGS, OR PASCO. TYPE FRITZ,SFRITZ,STAGS, OR PASCO.
R	FRITZ ,SFRITZ ,STAGS , OR PASCO IF RESPONSE TO QUESTION 1 IS NO GO TO QUESTION 5
3	WHAT IS THE MAXIMUM NUMBER OFTIMES YOU WISH TO PASS CANDIDATE DESIGNS THROUGH THE OPTIMIZER (A MAXIMUM VALUE WOULD BE M=10. A GOOD AVERAGE NUMBER TO USE IS M=4 OR M=5. M=")
R	TYPE A NUMBER FOR M
4	IF THE CURRENT DESIGN IS TO BE DISPLAYED AFTER EACH N PASSAGES THROUGH THE OPTIMIZER, WHAT IS N...
R	TYPE A NUMBER FOR N
5	ARE THE STRUCTURAL ANALYSIS OR THE OPTIMIZATION ANALYSIS TO BE PERFORMED FOR MORE THAN ONE COMBINATION OF INPLANE LOADS
R	YES OR NO IF RESPONSE IS NO GO TO QUESTION 8
6	THE NUMBER OF IN-PLANE LOAD COMBINATIONS,NLOADS=
R	TYPE A NUMBER FOR NLOADS
7	LOAD COMBINATION NO."I" NX,NY,NXY=
R	TYPE VALUES FOR NX,NY,NXY QUESTION 7 IS REPEATED NLOAD TIMES
8	NEXT, INDICATE BOUNDARY CONDITIONS ON EACH OF THE FOUR EDGES OF THE PANEL. ON THE ITH EDGE... IBOUND(I)=1 MEANS SIMPLE SUPPORT (ANTISYMMETRY) IBOUND(I)=2 MEANS CLAMPED IBOUND(I)=3 MEANS FREE IBOUND(I)=4 MEANS SYMMETRY IF THE PANEL IS CYLINDRICAL, THE CURVED EDGES ARE EDGES NOS. 1 AND 3. IBOUND(I),I=1,4) =
R	TYPE THE 4 VALUES FOR IBOUND(I)
9	NOTE...WITH PASCO ANALYSIS PANEL EDGES NO. 1 AND NO. 3 MUST BE SIMPLY SUPPORTED. THE BOUNDARY CONDITION

```
        INDICATORS ARE BEING CHANGED ACCORDINGLY......
 R      NO RESPONSE NECESSARY
10      NEXT, PROVIDE AN INDICATOR FOR STIFFENERS AT THE PANEL
        EDGES. THERE ARE THREE CHOICES ...
           (1) NO STIFFENERS AT THE EDGES
           (2) STIFFENERS AT THE EDGES WHICH ARE IDENTICAL TO
               THOSE NOT AT THE EDGES
           (3) STIFFENERS AT THE EDGES WHICH HAVE HALF THE
               STIFFNESS AND WEIGHT AS THOSE NOT AT THE EDGES.
               (THIS CHOICE CORRESPONDS TO A REFLECTION OF
                THE PANEL ABOUT THE DEGES.)
        ARE THERE STIFFENERS AT THE EDGES...
 R      YES OR NO
        IF RESPONSE IS NO, GO TO QUESTION 12
11      DO THE EDGE STIFFENERS HAVE HALF THE STIFFNESS AND
        WEIGHT AS THOSE NOT AT THE EDGES....
 R      YES OR NO
12      OPTIMIZATION IS PERFORMED IN THE PRESENCE OF CERTAIN
        CONSTRAINTS.  FIVE TYPES OF CONSTRAINTS ARISE FROM...
           (1) BUCKLING
           (2) MAXIMUM STRAIN
           (3) MAXIMUM STRESS
           (4) OTHER (DO NOT USE THIS OPTION)
           (5) VIBRATION FREQUENCY SPECTRUM (PASCO ONLY)
        YOU WILL NEXT BE ASKED WHICH OF THES TYPES OF  ARE
        CONSTRAINTS PRESENT IN THE CURRENT DESIGN PROBLEM.
        MIGHT BUCKLING CONSTRAIN THE DESIGN...
 R      YES OR NO
13      MIGHT MAXIMUM ALLOWABLE STRAIN CONSTRAIN THE DESIGN...
 R      YES OR NO
14      MIGHT MAXIMUM ALLOWABLE STRESS CONSTRAIN THE DESIGN...
 R      YES OR NO
15      MIGHT OTHER CONDITIONS CONSTRAIN THE DESIGN...
 R      YES OR NO
16      MIGHT FREQUENCY SPECTRUM CONSTRAIN THE DESIGN...
 R      YES OR NO
        IF RESPONSE IS NO GO TO QUESTION 18
17      PROVIDE FREQUENCY CONSTRAINTS FOR NLOADS IN-PLANE
        LOAD COMBINATIONS, (FREQ(I),I=1,NLOADS)=
 R      TYPE VALUES FOR FREQUENCY
18      DO YOU WISH TO USE DEFAULT VALUES FOR OPTIMIZATION
        STRATEGY...
 R      YES OR NO
        IF RESPONSE IS YES GO TO QUESTION 20
 19     READ STRATEGY PARAMETERS (REF)...
           SMOVE,SFACT,IPRINT,DELDV =
 R      TYPE THE VALUES FOR SMOVE,SFACT,IPRINT,AND DELDV
 20     DO YOU WISH TO USE A DEFAULT VALUE (.001) FOR THE
        CONVERGENCE CRITERION ON THE DECISION VARIABLES...
 R      YES OR NO
        IF RESPONSE IS YES GO TO QUESTION 22
21      CONVERGENCE CRITERION,  DDV=
 R      TYPE A VALUE FOR DDV
22      DO YOU WISH TO INPUT STAGS DATA
 R      YES OR NO
```

```
        IF RESPONSE IS NO GO TO QUESTION 50 (END INPUT)
 23     TOTAL NUMBER OF STAGS GENERAL INSTABILITY AND LOCAL
        INSTABILITY MODELS, NMODELS=
        (USE NMODELS=1 OR NMODELS=2 ONLY)
  R     TYPE VALUE FOR NMODELS
 24     FOR EACH MODEL INDICATE WHETHER IT IS FOR GENERAL
        INSTABILITY OR FOR LOCAL INSTABILITY, AND INDICATE THE
        DISCRETIZATION DENSITY (NUMBER OF ROWS AND COLUMNS)..
 25     IS MODEL NO. I FOR GENERAL INSTABILITY....
  R     YES OR NO
 26     NUMBER OF ROWS AND COLUMNS FOR THE I TH STAGS MODEL
        NROWS,NCOLS=
  R     TYPE VALUES FOR NROWS AND NCOLS
        REPEAT QUESTIONS 25 AND 26 NMODELS TIMES
MODES FOR SFRITZ AND FRITZ NOT INTERACTIVE
        TYPE NUMBER OF MODES FOR EACH MODEL
        TYPE MODE NUMBER,DISPLACEMENT,NUMBER OF AXIAL HALF
        WAVES,NUMBER OF TRANSVERSE HALF WAVES FOR EACH
        MODEL
        FOR FRITZ TYPE IPDR,IPOLY,ITEST
 50     END INPUT TO STORE
```

Following is a sample data set for program STORE.

Question Number	Input
1	YES
2	FRITZ
3	10
4	1
5	NO
8	1 1 1 1
10	NO
12	YES
13	NO
14	NO
15	NO
16	NO
18	NO
19	.2 .8 1 .005
20	NO
21	.03
22	NO

APPENDIX C

PROCEDURE FILE ECHOP

A number of procedures are on file ECHOP to aid the user in executing ECHO. These procedures are written in CYBER control language (CCL) for the CDC NOS/BE operating system. CCL is a set of statements and functions that a user can place in the control statement record of a job to initiate tests, transfer control of job processing, and perform looping (see appropriate CDC manual for details of CCL). Here, the control statements are in procedure files. The name of each file is denoted by

.PROC,ECHOXX.

in which XX are two characters to denote a particular file. A procedure file on ECHOP is executed by the control statement

BEGIN,ECHOPXX,ECHOP.

The following summarizes the procedure files availiable on ECHOP:

Procedure File Name	Purpose
ECHOHE	This procedure is for printing information about ECHO.
ECHOCI	This procedure is for executing ECHO when (ECHO DATA) is on cards. All required input is supplied by user.
ECHOFI	This procedure is for executing ECHO when (ECHO DATA) is on file DATE. All required input is supplied by user.
ECHOFG	This procedure is for initial optimization or structural analyses using the hardwired option. Multiple cases can be run and each new (GEOMETRY FILE) can be cataloged by the user.
ECHOGF	This procedure is for initial or continuation of optimization or structural analyses using the hard-wired option. Multiple cases can be run and each new (GEOMETRY FILE) can be cataloged by the user.
ECHOPE	This procedure is for transforming initial sizing data from PANDA to an ECHO (GEOMETRY FILE). Multiple cases can be run and each new (GEOMETRY FILE) can be cataloged by the user.
ECHOFU	This procedure is for updating a (GEOMETRY FILE) by data given in a (GEOMETRY DATA) file. Multiple cases can be run and each new (GEOMETRY FILE) can

be cataloged. No analysis is performed during this update.

ECHOGO — This procedure is for optimization using the hard-wired option. A case is optimized then the resulting geometry is used as starting values for the next case. Multiple cases can be run and each new (GEOMETRY FILE) can be cataloged by the user.

ECHOSD — This procedure is for generating STAGS/FRITZ input data to be used by RRSYS for a nonlinear analysis. Multiple cases can be run and each set of input data is written on a file which can be cataloged by the user.

ECHOEX — This procedure is for executing an example case.

Following is a listing of the procedure files with comments and typical runstreams (control statements and data). Note that (EOR) denotes an end-of-record mark (789 punch in column 1 on a card) and that (EOF) denotes and end-of-file mark (6789 punch in column 1 on a card). Cataloged files are attached by the control statement- ATTACH(LFN,MYFILE,CY=N)
in which LFN is a local file name, MYFILE is the name used when the file was cataloged, and N denotes the cycle number. To catalog a file the user must supply the control statement
CATALOG(LFN,MYFILE1)
in which MYFILE1 is the name under which the file is to be cataloged. Note that the request control statements are included in the procedures.

Procedure ECHOHE

```
.PROC,ECHOHE.
.* THIS PROCEDURE IS FOR PRINTING INFORMATION ABOUT ECHO.
.* THE  INFORMATION IS ON FILE ECHOI.
.* RUNSTREAM
.* (JOB CARD)
.* BEGIN,ECHOHE,ECHOP.
.* (EOF)
.* END RUNSTREAM
ATTACH(B,ECHOI,MR=1)
COPYBF(B,HEP)
REWIND(HEP)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
EXIT(U)
REVERT.
.DATA,DATE
HELP
```

```
HELP 1
HELP 2
HELP 3
HELP 4
HELP 5
HELP 6
HELP 7
END
0
.EOF
```

Procedure ECHOCI

```
.PROC,ECHOCI.
.* THIS PROCEDURE IS FOR EXECUTING ECHO WHEN (ECHO DATA) IS ON
.* CARDS. ALL REQUIRED INPUT IS SUPPLIED BY USER.
.* RUNSTREAM
.* (JOB CARD)
.* BEGIN,ECHOCI,ECHOP.
.* (EOR)
.*   (DATA CARDS FOR CASE)
.* (EOF)
.* END RUNSTREAM
ATTACH(B,ECHOI,MR=1)
COPYBF(B,HEP)
REWIND(HEP)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
ECHO(,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
EXIT(U)
REVERT.
```

Procedure ECHOFI

```
.PROC,ECHOFI.
.* THIS PROCEDURE IS FOR EXECUTING ECHO WHEN (ECHO DATA) IS ON
.* FILE DATE. ALL REQUIRED INPUT IS SUPPLIED BY USER.
.* THE USER MUST ATTACH THE FILE WITH LFN  DATE.
.* RUNSTREAM
.* (JOB CARD)
.* ATTACH(DATE,MYFILE1)
.* BEGIN,ECHOFI,ECHOP.
.* (EOF)
.* END RUNSTREAM
ATTACH(B,ECHOI,MR=1)
COPYBF(B,HEP)
REWIND(DATE)
REWIND(HEP)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
```

```
EXIT(U)
REVERT.
```

Procedure ECHOFG

```
.PROC,ECHOFG.
.* THIS PROCEDURE IS FOR INITIAL OPTIMIZATION OR STRUCTURAL
.* ANALYSES USING THE HARDWIRED OPTION. MULTIPLE CASES CAN BE
.* RUN AND EACH NEW (GEOMETRY FILE) CAN BE CATALOGED BY THE USER.
.* THE (GEOMETRY DATA) IS ON FILE WITH LFN AS DATGR.
.* DATGR MAY HAVE MULTIPLE RECORD OF (GEOMETRY DATA) FOR
.* DIFFERENT CASES.
.* (OEXEC DATA) IS NOT REQUIRED.
.* (GEOMETRY FILE) IS NOT REQUIRED.
.* (STATE FILE) IS NOT REQUIRED.
.* (ECHO DATA) IS ON FILE DATE AS DEFINED IN THIS PROCEDURE.
.* KRUN MUST BE 3 IN  (GEOMETRY DATA).
.* THIS PROCEDURE EXECUTES ECHO FOR EACH CASE DEFINED BY THE
.* (GEOMETRY DATA) ON DATGR. AFTER EXECUTION THE NEW (GEOMETRY
.* FILE) IS COPIED TO FILE EC. EC CAN BE CATALOGED AT END OF RUN.
.* A TYPICAL RUNSTREAM
.* (JOB CARD)
.* ATTACH(DATGR,MYFILE1)
.* BEGIN,ECHOFG,ECHOP.
.* CATALOG(EC,MYFILE2)
.* (EOF)
.* END RUNSTREAM
REQUEST(EC,*PF)
REWIND(EC)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
REWIND(DATGR)
SET(R1=20)
WHILE,(R1.EQ.20),LABEL1.
REWIND(DATG)
COPYBR(DATGR,DATG)
IFE,(.NOT.FILE(DATGR,EOF)),LABEL2.
REWIND(DATG)
REWIND(DATE)
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
REWIND(RDA)
COPYBF(RDA,EC)
ENDW,LABEL1.
ENDIF,LABEL2.
EXIT(U)
REVERT.
.DATA,DATE
INPUT
-2 0 0 0
DATG
.EOR
OEXEC
.EOR
```

```
END
0
.EOF
```

Procedure ECHOGF

```
.PROC,ECHOGF.
.* THIS PROCEDURE IS FOR INITIAL OR CONTINUATION OF OPTIMIZATION
.* OR STRUCTURAL ANALYSES USING THE HARDWIRED OPTION.
.* MULTIPLE CASES CAN BE RUN AND EACH NEW (GEOMETY FILE) CAN BE
.* BE CATALOGED BY THE USER.
.* THE (GEOMETRY DATA) IS ON FILE WITH LFN AS DATG.
.* DATG HAS ONE RECORD OF (GEOMETRY DATA).
.* (OEXEC DATA) IS NOT REQUIRED.
.* THE (GEOMETRY FILE) IS ON FILE WITH LFN AS PD.
.* PD MAY HAVE MULTIPLE FILES OF (GEOMETRY FILE) FOR DIFFERENT
.* CASES.
.* (STATE FILE) IS NOT REQUIRED.
.* (ECHO DATA) IS ON FILE DATE AS DEFINED IN THIS PROCEDURE.
.* KRUN MUST BE 3 IN  (GEOMETRY DATA).
.* THIS PROCEDURE EXECUTES ECHO FOR EACH CASE DEDFINED BY THE
.* (GEOMETRY FILE) AND UPDATED BY THE (GEOMETRY DATA). THE NEW
.* (GEOMETRY FILE) IS COPIED TO FILE EC. EC CAN BE CATALOGED AT
.* END OF RUN.
.* A TYPICAL RUNSTREAM
.* ATTACH(DATG,MYFILE1)
.* ATTACH(PD,MYFILE2)
.* BEGIN,ECHOGF,ECHOP.
.* CATALOG(EC,MYFILE3)
.* (EOF)
.* END RUNSTREAM
REWIND(PD)
REQUEST(EC,*PF)
REWIND(EC)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
SET(R1=20)
WHILE,(R1.EQ.20) ,LABEL1.
REWIND(RDA)
COPYBF(PD,RDA)
IFE,(.NOT.FILE(PD,EOI)),LABEL2.
REWIND(RDA)
REWIND(DATE)
REWIND(DATG)
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
REWIND(RDA)
COPYBF(RDA,EC)
ENDW,LABEL1.
ENDIF,LABEL2.
EXIT(U)
.DATA,DATE
INPUT
-2 0 -2 0
```

```
DATG
RDA
.EOR
OEXEC
.EOR
END
0
.EOF
```

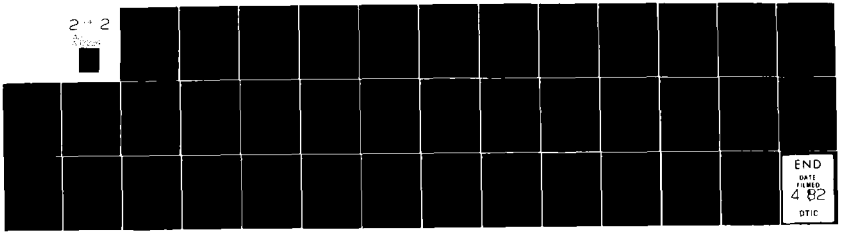
Procedure ECHOPE

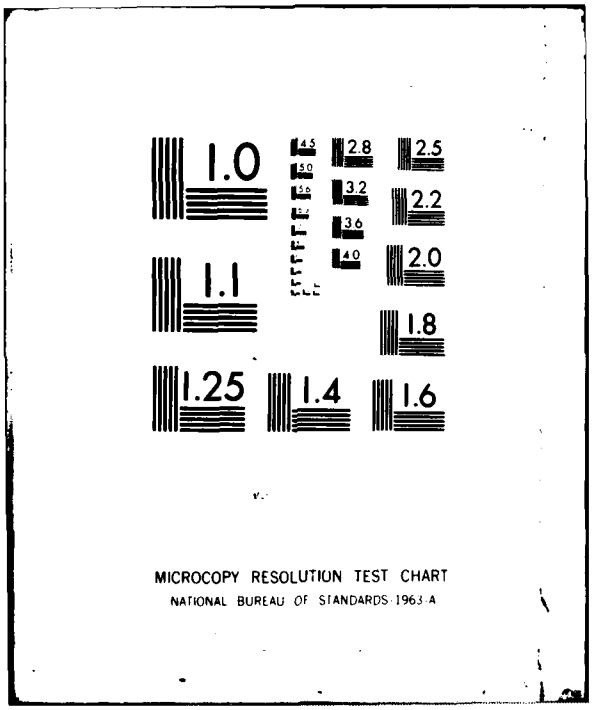
```
.PROC,ECHOPE.
.* THIS PROCEDURE IS FOR TRANSFORMING INITIAL SIZING DATA FROM
.* PANDA TO AN ECHO (GEOMETRY FILE).
.* MULTIPLE CASES CAN BE RUN AND EACH NEW (GEOMETRY FILE) CAN
.* BE CATALOGED BY THE USER.
.* PANDA DATA IS ON FILE WITH LFN AS P.
.* P MAY HAVE MULTIPLE FILES OF PANDA DATA FOR DIFFERENT CASES.
.* DATA IS REQUIRED BY PROGRAM STOR1 AND IS ON FILE DAT.
.* SEE APPENDIX C FOR REQUIRED DATA.
.* THIS PROCEDURE EXECUTES STORE FOR EACH CASE DEFINED IN THE
.* PANDA DATA WITH THE DATA (DAT). A (GEOMETRY FILE) IS
.* CREATED FOR EACH CASE AND COPIED TO FILE E. E CAN BE
.* CATALOGED AT END OF RUN.
.* RUNSTREAM
.* (JOB CARD)
.* ATTACH(P,MYFILE1)
.* ATTACH(DAT,MYFILE2)
.* BEGIN,ECHOPE,ECHOP.
.* CATALOG(E,MYFILE3)
.* (EOF)
.* END RUNSTREAM
REQUEST(E,*PF)
REWIND(E)
REWIND(P)
ATTACH(STOR1,MR=1)
SET(R1=20)
WHILE,(R1.EQ.20),LABEL1.
REWIND(TAPE1)
COPYBF(P,TAPE1)
IFE,(.NOT.FILE(P,EOI)),LABEL2.
REWIND(TAPE1)
REWIND(DAT)
STOR1(DAT)
REWIND(TAPE2)
COPYBF(TAPE2,E)
ENDW,LABEL1.
ENDIF,LABEL2.
RETURN(STOR1)
REVERT.
EXIT(U)
```

Procedure ECHOFU

```
.PROC,ECHOFU.
. THIS PROCEDURE IS FOR UPDATING A (GEOMETRY FILE) BY DATA GIVEN
.* IN A (GEOMETRY DATA) FILE. MULTIPLE CASES CAN BE RUN AND EACH
.* NEW (GEOMETRY FILE) CAN BE CATALOGED. NO ANALYSIS IS PERFORMED
.* DURING THIS UPDATE.
.* THE (GEOMETRY DATA) IS ON FILE WITH LFN AS DATG.
.* DATG HAS ONE RECORD OF (GEOMETRY DATA).
.* (OEXEC DATA) IS NOT REQUIRED.
.* THE (GEOMETRY FILE) IS ON FILE WITH LFN AS E.
.* E MAY HAVE MULTIPLE FILES OF (GEOMETRY FILE) FOR DIFFERENT
.* CASES.
.* (STATE FILE) IS NOT REQUIRED.
.* (ECHO DATA) IS ON FILE DATE AS DEFINED IN THIS PROCEDURE.
.* KRUN MUST BE 3 IN  (GEOMETRY DATA).
.* THIS PROCEDURE EXECUTES ECHO BUT NOT OEXEC FOR EACH CASE
.* DEFINED ON FILE E AND UPDATED BY THE (GEOMETRY DATA). THE
.* NEW (GEOMETRY FILE) IS COPIED TO FILE EE. EE CAN BE CATALOGED
.* AT END OF RUN.
.* NOTE THAT THE (GEOMETRY DATA) NEED ONLY CONTAIN CHANGES TO BE
.* MADE IN THE PROBLEM DESCRIPTION DEFINED BY THE (GEOMETRY
 FILE).
.* A TYPICAL RUNSTREAM
.* (JOB CARD)
.* ATTACH(E,MYFILE1)
.* ATTACH(DATG,MYFILE2)
.* BEGIN,ECHOFU,ECHOP.
.* CATALOG(EE,MYFILE3)
.* (EOF)
.* END RUNSTREAM
REQUEST(EE,*PF)
REWIND(E)
REWIND(EE)
ATTACH,ECHO,AECHO,MR=1.
REDUCE.
SET(R1=20)
WHILE,(R1.EQ.20),LABEL1.
REWIND(RDA)
COPYBF(E,RDA)
IFE,(.NOT.FILE(E,EOI)),LABEL2.
REWIND(RDA)
REWIND(DATE)
REWIND(DATG)
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
REWIND(RDA)
COPYBF(RDA,EE)
ENDW,LABEL1.
ENDIF,LABEL2.
.DATA,DATE
INPUT
-2 0 -2 0
DATG
RDA
.EOR
```

AD-A112 224 LOCKHEED MISSILES AND SPACE CO INC PALO ALTO CA PALO --ETC F/G 1/3
PANEL OPTIMIZATION WITH INTEGRATED SOFTWARE (POIS). VOLUME II. --ETC(U)
MAR 81 P STERN, B O ALMROTH, P STEHLIN F33615-76-C-3105
UNCLASSIFIED AFWAL-TR-81-3073-VOL-2 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

```
END
0
.EOF
```

Procedure ECHOGO

```
.PROC,ECHOGO.
.* THIS PROCEDURE IS FOR OPTIMIZATION USING THE HARDWIRED OPTION.
.* A CASE IS OPTIMIZED THEN THE RESULTING GEOMETRY IS USED AS
.* STARTING VALUES FOR THE NEXT CASE. MULTIPLE CASES CAN BE RUN
.* AND EACH NEW (GEOMETRY FILE) CAN BE CATALOGED BY THE USER.
.* THE (GEOMETRY DATA) IS ON FILE WITH LFN AS DATGR.
.* DATGR MAY HAVE MULTIPLE RECORDS OF (GEOMETRY DATA) FOR
.* DIFFERENT CASES.
.* (OEXEC DATA) IS NOT REQUIRED.
.* (GEOMETRY FILE) IS NOT REQUIRED.
.* (STATE FILE) IS NOT REQUIRED.
.* (ECHO DATA) IS ON FILE DATE AS DEFINED IN THIS PROCEDURE.
.* KRUN MUST BE 3 IN  (GEOMETRY DATA).
.* A TYPICAL RUNSTREAM
.* (JOB CARD)
.* ATTACH(DATGR,MYFILE1)
.* BEGIN,ECHOGO,ECHOP.
.* CATALOG(EC,MYFILE2)
.* (EOF)
.* END RUNSTREAM
REQUEST(EC,*PF)
REWIND(EC)
REDUCE.
ATTACH,ECHO,AECHO,MR=1.
REWIND(DATGR)
COPYBR(DATGR,DATG)
REWIND(DATG)
COPYBF(DATB,DATE)
REWIND(DATE)
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
REWIND(RDA)
COPYBF(RDA,EC)
REWIND(RDA)
SET(R1=20)
WHILE,(R1.EQ.20),LABEL1.
REWIND(DATG)
COPYBR(DATGR,DATG)
IFE,(.NOT.FILE(DATGR,EOF)),LABEL2.
REWIND(DATG)
REWIND(DATC)
REWIND(DATE)
COPYBF(DATC,DATE)
REWIND(DATE)
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
REWIND(RDA)
COPYBF(RDA,EC)
```

```
REWIND(RDA)
ENDW,LABEL1.
ENDIF,LABEL2.
EXIT(U)
REVERT.
.DATA,DATB
INPUT
-2 0 0 0
DATG
.EOR
OEXEC
.EOR
END
0
.EOF
.DATA,DATC
INPUT
-2 0 -2 0
DATG
RDA
.EOR
OEXEC
.EOR
END
0
.EOF
```

Procedure ECHOSD

```
.PROC,ECHOSD.
.* THIS PROCEDURE IS FOR GENERATING STAGS/FRITZ INPUT DATA TO BE
.* USED BY RRSYS FOR A NONLINEAR ANALYSIS. MULTIPLE CASES CAN BE
.* RUN AND EACH SET OF INPUT DATA IS WRITTEN ON A FILE WHICH CAN
.* BE CATALOGED BY THE USER.
.* THE (GEOMETRY DATA) IS ON FILE WITH LFN AS DATG.
.* DATG HAS ONE RECORD OF (GEOMETRY DATA).
.* A TYPICAL RUNSTREAM
.* (JOB CARD)
.* ATTACH(E,MYFILE1)
.* ATTACH(DATG,MYFILE2)
.* BEGIN,ECHOSD,ECHOP.
.* CATALOG(SDA,MYFILE3)
.* (EOF)
.* END RUNSTREAM
REQUEST(SDA,*PF)
REWIND(SDAT)
REWIND(E)
REWIND(DATG)
REDUCE.
.* ATTACH THE PROGRAM ECHO
ATTACH,ECHO,AECHO,MR=1.
SET(R1=20)
WHILE,(R1.EQ.20),LABEL1.
REWIND(RDA)
```

```
COPYBF(E,RDA)
IFE,(.NOT.FILE(E,EOI)),LABEL2.
REWIND(RDA)
REWIND(DATG)
REWIND(DATE)
REWIND(DATO)
ECHO(DATE,,PF,HEP,RDA,STA)
BEGIN,PFF,PF.
REWIND(DAT)
COPYBF(DAT,SDAT)
ENDW,LABEL1.
ENDIF,LABEL2.
EXIT(U)
REVERT.
.* THIS IS THE FILE DATE
.DATA,DATE
INPUT
-2 -2 -2 0
DATG
DATO
RDA
.EOR
OEXEC
.EOR
END
0
.EOF
.*  THIS IS FILE DATO  (OEXEC DATA)
.DATA,DATO
9 0 0
1 0 0
.EOF
```

Procedure ECHOEX

```
.PROC,ECHOEX.
.* THIS PROCEDURE IS FOR EXECUTION OF EXAMPLE 3,A WIDE PL
BEGIN,ECHOGO,ECHOP.
.DATA,DATGR
TITLE
    EXAMPLE 3,WIDE PLATE,BLADE STRINGERS,THICK,OPTIMIZE,FRITZ
CONTROL
2 -1 1  3 15 1 0 1
LOAD
1 -2000. 0. 0.
MATERIAL
1 10.+6 0. 0. .3 .1 0. 0.
BOUNDARY
1 4 1 4
PANEL
2 1 0 0
10. 7.5 0.
STIFFENER
1 1 0
1.0
```

```
1 0. 0
THICKNESS
2 1
.14 0. 1
.2 0. 1
WALL
2 1 0  1 1  1 2  1 2
CONSTRAINT
1 1  1.
DECISION
1  1 1  0 0
5. .5 .5  .1 .01 .01
OPTIMIZE
.2 .8  0 .005  .01
STAGS
2  0 2  5 7 5 7  9 6
1 3 1 0  2 2 1 0  3 1 1 0
4 3 1 2  5 2 1 2  6 1 1 2
7 3 1 4  8 2 1 4  9 1 1 4
1 3 1 1  2 3 1 3  3 3 1 5
4 3 2 1  5 3 2 3  6 3 2 5
0 2 0
END
.EOR
TITLE
    EXAMPLE 3,WIDE PLATE,BLADE STRINGERS,SIMUL,OPTIMIZE,FRITZ
STIFFENER
1 1 0
1.0
1 0. 0
THICKNESS
2 1
.14 0. 1
.06 0. 1
OPTIMIZE
.2 .8  0 .005  .002
STAGS
3  0 3 4  5 7 5 4 5 4  9 1 3
1 3 1 0  2 2 1 0  3 1 1 0
4 3 1 2  5 2 1 2  6 1 1 2
7 3 1 4  8 2 1 4  9 1 1 4
1 0 1 1
1 3 1 2  2 3 1 3  3 3 1 4
0 2 0
END
.EOF
```

APPENDIX D
BASIC THEORY FOR THE FRITZ PROGRAM

A straightforward finite element approach in structural panel optimization will still lead to computer costs well above any rational upper limit. Since we are interested in the interaction between local and global buckling modes, the grid in a finite element model covering the entire surface must be fine enough to accurately represent the local modes. For example, a square stringer-stiffened panel with five bays would require a model with some twenty elements in each direction. To perform a nonlinear analysis on such a model some 200 times is out of the question.

The number of degrees of freedom of the system must be drastically reduced. Such a reduction can be achieved by use of a Rayleigh-Ritz type approach, i.e., the structural displacements are confined to a space that is spanned by a number of global trial functions (compare Reference D-1). This approach was widely used before the heydays of finite element analysis. It was abandoned partly because of difficulties in treating structures of more general nature. Lately (in Reference D-2, for example) it has been suggested that global functions be used in connection with a finite element model. The finite element model, then, is used for the numerical integration yielding the coefficients in the reduced system. This procedure is clearly suitable for application in the present structural optimization program.

The second phase of the optimization involves only bifurcation buckling analysis. In that case it is possible to obtain local buckling loads by modeling a small part of the structure. The general instability load can be obtained from a model with smeared stiffeners. This may be somewhat inaccurate, but an adjustment of the critical load can be made in the third phase. Particularly in the presence of shear loading the computer time remains relatively high.

Therefore, a computer program module has been derived for eigenvalue analysis with global functions. The user of the program defines a number of terms in a two-dimensional Fourier series, and eigenvectors are sought in the space defined by all linear combinations of these terms.

In the case of buckling of a flat plate subjected to pure shear, it was found that a five-term series is sufficient to represent the buckling mode. In that case the error introduced due to the restriction of the solution space is about one percent, while the computer time required for the solution is reduced by a factor of five.

In the special case of panels stiffened in one direction only and simply supported at the edges normal to the stiffeners, all buckling modes, local as well as global, are represented as sine-functions in the coordinate direction parallel to the stiffeners. In that case it is possible to use a "one-dimensional" computer program such as VIPASA for all modes, general or local. The software for Phase Two, therefore, includes the use of VIPASA as one option. The second option is to use STAGSC-1, with local and general instability considered separately. The program user is allowed, if the second option must be chosen (two-way stiffening or clamped edges), to obtain a solution for a STAGSC-1 model by use of the Fourier series approach.

In order to reduce the number of terms used in the Fourier series, we express the inplane displacements in terms of the normal displacements by use of the equilibrium equations

$$\begin{aligned} N_{x,x} + N_{xy,y} &= 0 \\ N_{y,y} + N_{xy,x} &= 0 \end{aligned} \qquad (D.1)$$

In the cylindrical coordinates (x, θ), $N_{xy,y} = N_{x\theta,\theta}/R$; $N_{y,y} = N_{\theta,\theta}/R$, and R is the radius of the cylinder. In the following, the y is used for both rectangular and cylindrical coordinates. The nonlinear terms in these equations need not be included for the computation of bifurcation buckling modes. However, the nonlinear form of these equations is required for the analysis in Phase Three of the optimization. Therefore, they are included from the beginning.

We have

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = [C_{ij}] \begin{Bmatrix} U_x + \frac{1}{2} W_x^2 \\ V_y + W/R + \frac{1}{2} W_y^2 \\ U_y + V_x W_x W_y \\ -W_{xx} \\ -W_{yy} \\ -2W_{xy} \end{Bmatrix} \tag{D.2}$$

The terms U_x^2, V_x^2 in ϵ_x and U_y^2, V_y^2 in ϵ_y have been omitted because their inclusion would cause serious complication while having a negligible effect on the results for a typical panel. From Equation D.2, we have

$$\begin{aligned} N_{x,x} &= \{C_{1i}\} \{\epsilon\}_{,x} \\ N_{xy,y} &= \{C_{3i}\} \{\epsilon\}_{,y} \\ N_{y,y} &= \{C_{2i}\} \{\epsilon\}_{,y} \\ N_{xy,x} &= \{C_{3i}\} \{\epsilon\}_{,x} \end{aligned} \tag{D.3}$$

where

$$\varepsilon_{,x} = \begin{Bmatrix} U_{xx} + W_x W_{xx} \\ V_{xy} + W_x/R + W_y W_{xy} \\ U_{xy} + V_{xx} + W_x + W_y W_{xx} \\ -W_{xxx} \\ -W_{xyy} \\ -2W_{xxy} \end{Bmatrix} \tag{D.4}$$

$$\varepsilon_{,y} = \begin{Bmatrix} U_{xy} + W_x W_{xy} \\ V_{yy} + W_y/R + W_y W_{yy} \\ U_{yy} + V_{xy} + W_x W_{yy} + W_y W_{xy} \\ -W_{xxy} \\ -W_{yyy} \\ -2W_{xyy} \end{Bmatrix} \tag{D.5}$$

For further simplification we make, at this point, the assumption that the effects of anisotropy are negligible, i.e., the coefficients C_{13}, C_{23}, C_{16}, C_{26}, C_{34}, and C_{35} are all omitted.

The first of Equations D.2 then leads to

$$L_1 + R_1 = 0 \tag{D.6}$$

where

$$L_1 = C_{11} U_{xx} + C_{33} U_{yy} + (C_{12} + C_{33}) V_{xy} \tag{D.7}$$

$$\begin{aligned} R_1 = {} & C_{11} W_x W_{xx} + C_{12} (W_x/R + W_y W_{xy}) - C_{14} W_{xxx} \\ & - C_{15} W_{xyy} + C_{33} (W_x W_{yy} + W_y W_{xy}) - 2C_{36} W_{xyy} \end{aligned} \tag{D.8}$$

The second of Equations D.7 leads to

$$L_2 + R_2 = 0 \tag{D.9}$$

where

$$L_2 = (C_{12} + C_{33})\, U_{xy} + C_{22}\, V_{yy} + C_{33}\, V_{xx} \tag{D.10}$$

$$R_2 = C_{12}\, W_x\, W_{xy} + C_{22}\,(W_y/R + W_y\, W_{yy}) - C_{24}\, W_{xxy} - C_{25}\, W_{yyy} + C_{33}\,(W_x\, W_{xy} + W_y\, W_{xx}) - 2C_{36}\, W_{xxy} \tag{D.11}$$

It is assumed that the normal displacement is of the form

$$W = \sum_{i=1}^{M} x_i \sin(m_i\, \pi\, y/LY) \sin(n_i\, \pi\, x/LX) \tag{D.12}$$

where m_i and n_i are vectors of integers each with M elements, LY is the panel width in degrees for cylindrical panels and in the unit of length for flat panels, LX is the panel length.

In the linear case Equations D.1 may be satisfied if

$$U = \sum_{i=1}^{M} a_i\, X_i \sin(m_i\, \pi y/LY) \cos(n_i\, \pi x/LX) \tag{D.13}$$

and

$$V = \sum_{i=1}^{M} b_i\, X_i \cos(m_i\, \pi y/LY) \sin(n_i\, \pi x/LX) \tag{D.14}$$

with

$$F_i = m_i \pi/(LY \cdot R)$$

$$G_i = n_i\, \pi/LX \tag{D.15}$$

$$H_i = m_i\, \pi/LY$$

$$
\begin{aligned}
U_{xx} &= -\sum a_i X_i G_i^2 \sin(H_i y) \cos(G_i x) \\
U_{xy} &= -\sum a_i X_i F_i G_i \cos(H_i y) \sin(G_i x) \\
U_{yy} &= -\sum a_i X_i F_i^2 \sin(H_i y) \cos(G_i x)
\end{aligned}
\tag{D.16}
$$

$$
\begin{aligned}
V_{xx} &= -\sum b_i X_i G_i^2 \cos(H_i y) \sin(G_i x) \\
V_{xy} &= -\sum b_i X_i G_i F_i \sin(H_i y) \cos(G_i x) \\
V_{yy} &= -\sum b_i X_i F_i^2 \cos(H_i y) \sin(G_i x)
\end{aligned}
\tag{D.17}
$$

$$
\begin{aligned}
W_x &= \sum X_i G_i \sin(H_i y) \cos(G_i x) \\
W_y &= \sum X_i F_i \cos(H_i y) \sin(G_i x) \\
W_{xx} &= -\sum X_i G_i^2 \sin(H_i y) \sin(G_i x) \\
W_{xy} &= \sum X_i F_i G_i \cos(H_i y) \cos(G_i x) \\
W_{yy} &= -\sum X_i F_i^2 \sin(H_i y) \sin(G_i x) \\
W_{xxx} &= -\sum X_i G_i^2 \sin(H_i y) \cos(G_i x) \\
W_{xxy} &= -\sum X_i F_i G_i^3 \cos(H_i y) \sin(G_i x) \\
W_{xyy} &= -\sum X_i F_i^2 G_i \sin(H_i y) \cos(G_i x) \\
W_{yyy} &= -\sum X_i F_i^2 \cos(H_i y) \sin(G_i x)
\end{aligned}
\tag{D.18}
$$

In the linear case

$$R_1 = C_{12} W_x/R - C_{14} W_{xxx} - C_{15} W_{xyy} - 2C_{36} W_{xyy}$$
$$R_2 = C_{22} W_y/R - C_{24} W_{xxy} - C_{25} W_{yyy} - 2C_{36} W_{xxy} \qquad (D.19)$$

or after substitution of Equations D.18

$$R_1 = \sum_{i=1}^{M} X_i \sin (H_i y) \cos (G_i x) (C_{12} G_i/R + C_{14} G_i^3 + C_{15} F_i^2 G_i + 2C_{36} F_i^2 G_i)$$
$$R_2 = \sum_{i=1}^{M} X_i \cos (H_i y) \sin (G_i x) (C_{22} F_i/R + C_{24} F_i G_i^2 + C_{25} F_i^3 + 2C_{36} F_i G_i^2) \qquad (D.20)$$

In a similar manner with Equations D.16 and D.17 the terms L_1 and L_2 (Equations D.7 and D.10) become

$$L_1 = -\sum_{i=1}^{M} X_i \sin (H_i y) \cos (G_i x) [a_i(C_{11} G_i^2 + C_{33} F_i^2) + b_i (C_{12} + C_{33}) F_i G_i]$$
$$L_2 = -\sum_{i=1}^{M} X_i \cos (H_i y) \sin (G_i x) [a_i (C_{12} + C_{33}) F_i G_i + b_i (C_{22} F_i^2 + C_{33} G_i^2)] \qquad (D.21)$$

Equations D.6 and D.9 after substitution of Equations D.20 and D.21 yield for each combination of harmonics two equations from which the coefficients a_i and b_i can be computed. These two equations are:

$$\begin{bmatrix} D_{11} & D_{12} \\ D_{12} & D_{22} \end{bmatrix} \begin{Bmatrix} a_i \\ b_i \end{Bmatrix} = \begin{Bmatrix} D_{10} \\ D_{20} \end{Bmatrix} \tag{D.22}$$

in which

$$\begin{aligned} D_{11} &= C_{11}\, G_i^2 + C_{33}\, F_i^2 \\ D_{12} &= (C_{12} + C_{33})\, F_i\, G_i \\ D_{22} &= C_{22}\, F_i^2 + C_{33}\, G_i^2 \\ D_{10} &= C_{14}\, G_i^3 + C_{15}\, F_i^2\, G_i + 2C_{36}\, F_i^2\, G_i + C_{12}\, G_i/R \\ D_{20} &= C_{24}\, F_i\, G_i^2 + C_{25}\, F_i^3 + 2C_{36}\, F_i\, G_i^2 + C_{22}\, F_i/R \end{aligned} \tag{D.23}$$

The solution of Equation D.22 is

$$\begin{aligned} a_i &= [(D_{22}\, D_{10} - D_{12}\, D_{20})/(D_{11}\, D_{22} - D_{12}^2)]_i \\ b_i &= [D_{11}\, D_{20} - D_{12}\, D_{10})/(D_{11}\, D_{22} - D_{12}^2)]_i \end{aligned} \tag{D.24}$$

In the bifurcation buckling analysis (Phase Two of the optimization), the program user specifies the Fourier terms for the lateral displacements (Equations D.12). The computer program includes for each W-term the corresponding Fourier terms for the inplane displacements (Equations D.13 and D.14) with the amplitudes, a_i and b_i, given by Equation D.24. The total number of degrees of freedom in the system is M.

The solution of the nonlinear problem in Phase Three of the optimization is somewhat more complex. The bending strain energy density at the integration points and consequently the contribution to the first and second variations can readily be computed by use of Equation D.12. The inplane displacements, including nonlinear terms, are of the form

$$U = \sum_{i=1}^{M} a_i X_i \sin (m_i \pi y/LY) \cos (n_i \pi x/LX + \sum_{p,}\sum_{q=0}^{2M} a_{ij} X_i X_j \cos (p \pi y/LY) \sin (q \pi x/LX) \quad (D.25)$$

and

$$V = \sum_{i=1}^{M} b_i X_i \cos (m_i \pi y/LY) \sin (n_i \pi x/LX) + \sum_{p,}\sum_{q=0}^{2M} b_{ij} X_i X_j \sin (p \pi y/LY) \cos (q \pi x/LX) \quad (D.26)$$

The linear part of the inplane displacement is given above (Equations D.22). The nonlinear parts of R_1 and R_2 (Equations D.8 and D.11) are developed in the following. There is a contribution to the inplane displacement from each term in the products of two series containing derivatives of W. In the computer program the summations will be introduced through a double loop, and it is sufficient here to define the contributions to U and V from a typical term in the product series.

For example, the term

$$\begin{aligned} C_{11} W_x W_{xx} &= -C_{11} [X_i G_i \sin (H_i y) \cos (G_i x)] \\ &\quad \cdot [X_j G_j^2 \sin (H_j y) \sin (G_j x)] \\ &= -\frac{1}{4} C_{11} G_i G_j^2 X_i X_j [\cos (H_i - H_j) y - \cos (H_i + H_j) y] \\ &\quad \cdot [\sin (G_i + G_j) x - \sin (G_i - G_j) x] \end{aligned} \quad (D.27)$$

with the notations

$$\begin{aligned} S1_{ij} &= \cos\left[(H_i - H_j)\, y\right] \sin\left[(G_i - G_j)\, x\right] \\ S2_{ij} &= \cos\left[(H_i - H_j)\, y\right] \sin\left[(G_i + G_j)\, x\right] \\ S3_{ij} &= \cos\left[(H_i + H_j)\, y\right] \sin\left[(G_i - G_j)\, x\right] \\ S4_{ij} &= \cos\left[(H_i + H_j)\, y\right] \sin\left[(G_i + G_j)\, x\right] \end{aligned} \tag{D.28}$$

becomes

$$C_{11}\, W_x\, W_{xx} = \frac{1}{4}\, C_{11}\, G_i\, G_j^2\, X_i\, X_j\, (S1_{ij} - S2_{ij} - S3_{ij} + S4_{ij}) \tag{D.29}$$

In the same way we find

$$\begin{aligned} (C_{12} + C_{33})\, W_y\, W_{xy} = \frac{1}{4}\, (C_{12} + C_{33})\, F_i\, F_j\, G_j\, X_i\, X_j\, (S1_{ij} \\ + S2_{ij} + S3_{ij} + S4_{ij}) \end{aligned} \tag{D.30}$$

and

$$C_{33}\, W_x\, W_{yy} = \frac{1}{4}\, C_{33}\, G_i\, F_j^2\, X_i\, X_j\, (S1_{ij} - S2_{ij} - S3_{ij} + S4_{ij}) \tag{D.31}$$

The nonlinear contributions to R_2 are derived in the same way. With the notations

$$\begin{aligned} C1_{ij} &= \sin\left[(H_i - H_j)\, y\right] \cos\left[(G_i - G_j)\, x\right] \\ C2_{ij} &= \sin\left[(H_i - H_j)\, y\right] \cos\left[(G_i + G_j)\, x\right] \\ C3_{ij} &= \sin\left[(H_i + H_j)\, y\right] \cos\left[(G_i - G_j)\, x\right] \\ C4_{ij} &= \sin\left[(H_i + H_j)\, y\right] \cos\left[(G_i + G_j)\, x\right] \end{aligned} \tag{D.32}$$

$$(C_{12} + C_{33})\, W_x\, W_{xy} = \frac{1}{4}\,(C_{12} + C_{33})\, G_i\, F_j\, G_j\, X_i\, X_j\, (C1_{ij} + C2_{ij} + C3_{ij} + C4_{ij}) \tag{D.33}$$

$$C_{22}\, W_y\, W_{yy} = \frac{1}{4}\, C_{22}\, F_i\, F_j^2\, X_i\, X_j\, (C1_{ij} - C2_{ij} - C3_{ij} + C4_{ij}) \tag{D.34}$$

$$C_{33}\, W_y\, W_{xx} = \frac{1}{4}\, C_{33}\, F_i\, G_j^2\, X_i\, X_j\, (C1_{ij} - C2_{ij} - C3_{ij} + C4_{ij}) \tag{D.35}$$

Corresponding to each of the products $X_i\, X_j$ we have contributions to four terms in the Fourier series for U and V. The nonlinear terms in R_1 and R_2 indicate that the solution must be in the form given in Equations D.25 and D.26. The contributions to the inplane displacement components can be written

$$U = \sum_{k=1}^{4} \alpha_k\, X_i\, X_j \cos(P_k\, y) \sin(Q_k\, x)$$
$$V = \sum_{k=1}^{4} \beta_k\, X_i\, X_j \sin(P_k\, y) \cos(Q_k\, x) \tag{D.36}$$

where

$$\begin{aligned} P_1 &= (H_i - H_j) \;;\; Q_1 = (G_i - G_j) \\ P_2 &= (H_i - H_j) \;;\; Q_2 = (G_i + G_j) \\ P_3 &= (H_i + H_j) \;;\; Q_3 = (G_i - G_j) \\ P_4 &= (H_i + H_j) \;;\; Q_4 = (G_i + G_j) \end{aligned} \tag{D.37}$$

The values for α_k and β_k are obtained from

$$\begin{Bmatrix} \alpha \\ \beta \end{Bmatrix}_k = \begin{bmatrix} D_{11} & D_{12} \\ D_{12} & D_{22} \end{bmatrix}_k^{-1} \begin{Bmatrix} R_1 \\ R_2 \end{Bmatrix}_k \tag{D.38}$$

in which

$$D_{11} = C_{11} Q_k^2 + C_{33} P_k^2$$
$$D_{12} = (C_{12} + C_{33}) P_k Q_k \qquad (D.39)$$
$$D_{22} = C_{22} P_k^2 + C_{33} Q_k^2$$

$$P = p \frac{\pi}{\theta} , \quad Q_k = \frac{q\pi}{L} \qquad (D.40)$$

$$\left.\begin{array}{lll} k = 1 : & R_1 = A + B + C \\ & R_2 = D + E + F \\ k = 2 : & R_1 = -A + B - C \\ & R_2 = D - E - F \\ k = 3 : & R_1 = -A + B - C \\ & R_2 = D - E - F \\ k = 4 : & R_1 = A + B + C \\ & R_2 = D + E + F \end{array}\right\} \qquad (D.41)$$

With

$$A = \frac{1}{4} C_{11} G_i G_j^2$$
$$B = \frac{1}{4} (C_{12} + C_{33}) F_i F_j G_j$$
$$C = \frac{1}{4} C_{33} G_i F_j^2 \qquad (D.42)$$
$$D = \frac{1}{4} (C_{12} + C_{33}) G_i F_j G_j$$
$$E = \frac{1}{4} C_{22} F_i F_j^2$$
$$F = \frac{1}{4} C_{33} F_i G_j^2$$

References

D-1 Seide, P. and Weingarten, V. I., "On the Buckling of Circular Cylindrical Shells Under Pure Bending," J. Appl. Mech., Vol. 28, pp. 112-116, 1961.

D-2 Almroth, B. O., Stern, P., and Brogan, F. A., "Automatic Choice of Global Functions in Structural Analysis," AIAA J., Vol. 16, pp. 525-528, 1978.

PART II, RRRSYS

SECTION 1

INTRODUCTION

In this part of the report a brief description is given of a package of computer program modules referred to as RRSYS. The primary function of RRSYS within the POIS program is to perform collapse or failure analysis of structural panels with random initial imperfections. For this purpose a Rayleigh-Ritz type analysis is used with the basis functions defined by the program user. As a part of the POIS system RRSYS can be used also for nonlinear static analysis of a finite element model. The analysis is then expedited by use of integration in a reduced space to yield initial estimate for solution with the Newton method. In this form RRSYS is primarily used for verification of results obtained by use of the more approximate programs and to study the deformation patterns to facilitate the choice of functions in a Rayleigh-Ritz type analysis.

The structural response to a given environment is described by the differential equations of motion of deformable bodies. Analytic solutions of such problems for a reasonably large class of structural configurations are not within the realm of the possible. Consequently, the mathematical problem is recast into a numerical problem for solution on the computer.

The output from the computer consists of a sequence of numbers, in some way representing the functions satisfying equilibrium equations and boundary conditions. If the solution is represented by a linear combination of a set of "basis functions" then the components of the output vector consist of the coefficients in this linear combination. This is the case if we use the Galerkin or Rayleigh-Ritz procedures. If we use the finite difference or finite element procedures, the solution function is represented by its values at a number of discrete locations within the structure. Because these discretized methods are readily applied in a computer program for a general type of structure, they have been gaining popularity. This applies in particular to the finite element method. The finite element method may be considered as a Rayleigh-Ritz analysis in which the basis functions are localized. Confusion is avoided if the classical form of the Rayleigh-Ritz analysis is referred to as the "Global Function Approach".

New technology in the space and energy fields has led to a growing demand for accurate analysis which at times cannot be met due to the limits set by available budget for computer time. In response to this need for more efficient numerical analysis, the possibilities have been explored of reducing the number of freedoms in the system through a revival of the global function approach. Nagy (Reference 1) analyzed trusses using buckling modes as Ritz functions.

This approach is straightforward if it can be assumed that the deformation is inextensional, but is not directly applicable if the strain energy due to

stretching of the neutral axis (middle surface for shells) must be included. A more general way to automatically select a suitable set of basis vectors and a method to control the accuracy of the solution was first presented in Reference 2. In that case, the global function approach is used in connection with a finite element model. The basis functions are represented by a set of basis vectors and the interpolating shape functions. Approximate solutions to the initial system are sought in the reduced space defined by all linear combinations of the basis vectors. We refer to the reduced space as the (infinite) set of trial vectors. Basis vectors can be obtained through solution of the initial (discrete) system and the accuracy of solutions in the reduced system can be assessed in the discrete system. Such procedures were further developed by Noor, References 3 and 4. In Reference 2, orthonormalized nonlinear solutions at different load levels are used as basis vectors while Noor proposed to use the so-called path derivatives. In both cases, the procedure involves a return to the discrete system (the finite element model) for evaluation of the error and automatic generation of new vectors when the size of the error suggests such action.

In a finite-element formulation of the structural problem, we have

$$M\ddot{X} + SX - F = 0 \tag{1}$$

where M is the mass matrix, S a nonlinear algebraic stiffness operator, and F the vector of external forces. The vector X represents the freedoms in the finite-element formulation; that is displacement and rotation components at the structural nodes.

A global function formulation may be obtained by introduction into the finite element formulation of the substitution

$$X = Tq \tag{2}$$

where each column in the matrix T represents one of the basis vectors. A basis function is defined by the finite-element discretization, i.e., by the displacement and rotation components at structural nodes and by the local shape functions peculiar to the element. The components of the vector q are coefficients in a linear combination of basis vectors. These coefficients are the degrees of freedom in a reduced nonlinear algebraic equation system obtained through substitution of Equation 2 into Equation 1 and summation over the elements. The ith equation is of the form

$$\bar{M}_i\ddot{q}_i + \Sigma\, A_{ij}q_j + \Sigma\Sigma B_{ijk}q_jq_k + \Sigma\Sigma\Sigma\, C_{ijkl}q_j\, q_k\, q_l = \bar{F}_i \tag{3}$$

$$(i,j,k,l, = 1,I)$$

where $\bar{M}$ and $\bar{F}$ are generalized masses and forces corresponding to the ith basis function. The nonlinear terms derive from the stiffness operator.

RRSYS consists of a number of separate processors which have access to the same data base. Included among these processors are the STAGSC-1 program and a processor RITZ which computes the coefficients in Equation 3 once a STAGS finite element model and a set of solution vectors, the T matrix, have been defined. The processor FRITZ discussed in Appendix D of this report also resides as a processor in RRSYS. A user of RRSYS can perform any function within the scope of the system by giving appropriate commands on procedure files.

Three special functions are of special interest to the user of POIS. Instructions in this volume are restricted to these functions.

SECTION 2

PROGRAM ORGANIZATION

RRSYS uses the STAGSC-1 structural analysis program to define a finite element representation of the model. Displacement solutions are found by computing the strain energy through numerical integration and minimizing it with respect to the freedoms of the system. The subspace solution is performed by a special module, which integrates the equations of motion as formulated in generalized coordinates. The case of static displacements is handled by neglecting terms containing time derivatives.

The following modules are presently being used in the Rayleigh-Ritz process:

Module	Function
DBS	Data base management module, used interactively or in batch mode. Serves for interactive data base operations.
STAGS1	Input module of the STAGSC-1 structural analysis program. Model definition.
STAGS2	Analysis module of STAGSC-1. Solves the so-called 'big' equation system.
MERGE	Transfers local STAGS data to data base, e.g. force-, mass-, displacement control and solution vectors. Performs automatic mode selection.
RITZ	Computes the coefficients of the expressions for potential energy, first and second variations in the Ritz space (sub-space). Orthonormalizes the displacement modes (basis vectors).

RRSTAGS	Sets up the reduced equation system pertaining to the Ritz space. Solves the reduced system (static) or performs time integratoin (dynamic). Also computes eigenvalues in the Ritz space (bifurcation load if static, eigenfrequencies if dynamic).
REST	Creates local STAGS files required for STAGS2 restart from data stored in the data base. Defines parameters controlling STAGS2 restart. Modifies existing local STAGS files for restart.
FRITZ	Computes the coefficients in the reduced system without reference to a finite element model. Solves buckling or collapse problems in the reduced system. Ritz functions are defined by user.
ADJ	Modifies the error criteria (error keys, return keys) used in RRSTAGS.
RRLIM	Computes location of limit point (collapse point).

In addition, there is one module, which is not directly part of the Rayleigh-Ritz process, but which is often used to verify correctness and accuracy of displacement solutions:

Module	Functions
FVAR	Computes first variation of the strain energy in the big system. Checks residuals and equilibrium error. Module is designed to be used interactively in prompting mode.

There is also a module for plotting the results, e.g. displacement solutions, buckling modes (STAPL). Since this module has no part in the Ritz process, no further mention will be made and the user is referred to the STAGSC-1 user manual, where STAPL is described (Reference 5).

The user instructions presented here are intended to cover the use of RRSYS as a part of POIS. RRSYS is still being extended. Complete instructions allowing utilization of the entire scope of RRSYS will be presented in a forthcoming NASA Contractor's Report (Reference 7).Some functions of RRSYS are of special importance in relation to the POIS System. One is a special procedure referred to as AUTORITZ. In this procedure the Ritz modes are automatically determined and updated through STAGSC-1 analysis. The procedure is discussed in detail in Section 3.

In connection with panel optimization the AUTORITZ procedure is primarily used to check the validity of analyses with user-defined functions or to give guidance in the choice of functions. Whenever user written functions are used these can either be defined in the program DBS with STAGSC-1 data read in on a

separate file or all input can be read from a file created in ECHO. In the latter case the ECHO output file will reside in the RRSYS database and can be edited by use of DBS. This may be necessary for instance if the permitted runtime in a nonlinear case must be increased. Hardwired procedure files are available for

1) nonlinear static runs with AUTORITZ

2) nonlinear run with FRITZ, input from ECHO

3) nonlinear run with user-defined vectors, i.e. the user defined functions are converted to solution vectors, input from ECHO. For these three cases the input decks (CDC, NOS/BE) are the following

AUTORITZ:

```
Job Card
REQUEST, IB1, *PF
REQUEST, IB3, *PF
COPYBR, INPUT, IB1.
COPYBR, INPUT, IB3.
CATALOG, IB1.
CATALOG, IB3.
RETURN, IB1, IB3.
BEGIN,, RR, IG = 1, IO = IB0, I1 = IB1, I3 = IB3, DBASE = IBDB.
7/8/9
STAGSC-1 input data (See STAGSC-1 Manual)
7/8/9
RRSTAGS input data (Section 5)
6/7/8/9
```

Nonlinear RRSTAGS run with user defined modes (input from ECHO) with or without user modes.

```
Job Card
COPYBR, INPUT, IB1.
COPYBR, INPUT, IB3.
BEGIN,, RRSYS, IG = 0, FL = IFL, I1 = IB1, I3 = IB3, OO = OUT.
7/8/9
RRSTAGS input data
6/7/8/9
```

Here IFL = Field length for STAGS execution
OUT = Name of output file

USERMODES and SELMODES (Section 4) input is included in the input data deck to RRSTAGS.

Nonlinear analysis in RRSYS with use of FRITZ.

```
Job Card
COPYBR, INPUT, IB5.
BEGIN,, RRSYS, IG = 1, I5 = IB5, OO = OUT.
7/8/9
FRITZ input
6/7/8/9
```

Here OUT = Name of output file.

The control cards for AUTORITZ analysis listed above include instructions to save the STAGSC-1 and RRSTAGS input data on permanent files. The REQUEST-and CATALOG-cards are optional, if they are left out the analysis will be performed but the input data will not be saved.

The options IG = 2 and IG = 3 in AUTORITZ (BEGIN,, ECHO, IG2 OR IG3...) are used for restart of an AUTORITZ run, IG2 for restart with a STAGSC-1 run and IG3 for restart in the reduced system with functions available in the data base. With IG = 0 or 5 solutions are not saved in the data base, so restart is not permitted.

SECTION 3

THE AUTORITZ PROCEDURE

The assemblage of computer program modules, RRSYS (Reference 6), is based on the use of global functions together with a finite element model. This assemblage includes the STAGSC-1 program (Reference 5). The structural model is always defined by STAGSC-1 input data. In nonlinear elastic analysis, the program user has options to define global functions (as input) or to obtain such functions through solution of the discrete system. Eigenmodes, buckling or vibration, or nonlinear solutions to the static equilibrium equations can be included (user's choice). A special procedure, AUTORITZ, features a problem-adaptive solution strategy in which automatic choice and continuous modification of certain strategy parameters allow for efficient analysis.

AUTORITZ is based on the ideas first proposed in Reference 2. In that case, the use of global functions represents a powerful way to determine initial estimates for iterative solution of the discrete system. Initial estimates are obtained through integration of a reduced displacement space spanned by the selected basis vectors. Successful operation of such software requires the availability of adequate methods for specification of the basis vectors and a satisfactory step size selector sensing when a return to the discrete system for updating is desirable. In References 3 and 4, Noor uses the path derivatives as basis vectors. These are defined in terms of the coefficients in Equation 3. Unfortunately, the number of distinct coefficients is very large and if many different elements are included in the structural model, severe data storage problems will result. Therefore, the basis vectors in

AUTORITZ are defined in terms of nonlinear solutions to the discrete system at different load levels. This is equivalent to the use of numerically determined path derivatives. The disadvantage in this case is that solution accuracy may limit the number of solutions that profitably can be included as basis vectors.

In Reference 3, Noor bases the return key on the change in structural stiffness parameter. A change by ten percent in the value of this parameter prompts return to the discrete system. In Reference 4 he uses, as in Reference 2, the norm of the error in the equation system for the discrete model. In both cases, the analysis is very efficient. In Reference 4, the collapse analysis of an axially compressed prismatic shell (the "pear shaped cylinder") is presented. Return to the discrete system is dictated by an error norm (normalized with respect to the norm of the load vector) exceeding 0.05. The load steps i.e. the load increments between returns to the discrete system in that case are very large; indicating a potential for substantial savings in computer cost in nonlinear elastic analysis.

Extensive experimentation with AUTORITZ has indicated that both a stiffness parameter and the error norm may be useful for step size control. However, suitable values of the parameters governing return to the discrete system are not only case dependent but in a given case they may also vary considerably with the load level. It appears that the potential for savings in computer time by use of global functions can only be realized if a problem-adaptive computational strategy is available. In AUTORITZ, the return key is adjusted in response to the characteristics of the problem so that an efficient analysis can be obtained in a variety of cases without preceding experimentation with the step size selection. The procedure involves a number of strategy parameters. A set of default values for these parameters has been selected to be used when the analyst lacks special knowledge of the behavior of his system and therefore declines to make a different choice.

Default Strategy

The initial basis vectors are obtained through solution by STAGSC-1. This program does not contain procedures for automatic choice of the initial load step. The user of RRSYS must define the initial load and the initial step in STAGSC-1. The user also defines the initial and the maximum numbers of basis vectors, N_i and N_m. Default values are $N_i = 4$, $N_m = 6$.

On each return to the discrete system, a nonlinear solution of this discrete system is obtained and included in the data base. If the number of basis vectors in the data base exceeds N_m, the program gives preference to those corresponding to higher load levels when the basis vectors are selected.

A check on linear dependence among the basis vectors is performed and vectors that are not sufficiently distinct are discarded. The number of basis vectors therefore can be less than N_i and remain less than N_m. During the computations, the program attempts to set the return key so that solution of the discrete system will require approximately five iterations. The stiffness parameter included in the strategy is represented by the diagonal elements in

the factored matrix corresponding to the reduced system. The following notations are used:

ε = error norm = $||\delta U||/||f||$ where δU is the first variation of the total potential energy (i.e., the residuals) and f is the vector of applied forces (including reactions).

A = vector of diagonal elements in the factored matrix associated with the reduced system.

$\overline{A}_i$ = ratio between present value of the elements of A and corresponding values at last return to the discrete system (initial values for the first step).

N = number of iterations for convergence at last return to the discrete system.

f = $10^{-k(N-5)}$ where k is an input constant.

Solution of the discrete system and updating of the set of basis vectors by inclusion of the current solution is dictated by any of the following events:

$$\begin{aligned} &1) \quad \varepsilon > \varepsilon_q \\ &2) \quad \overline{A}_i > \delta_U \text{ for some } i \\ &3) \quad \overline{A}_i < \delta_L \text{ for some } i \\ &4) \quad \Delta P \text{ is reached (max load step)} \end{aligned} \tag{4}$$

where ε_q, δ_U, δ_L are input parameters.

Whenever convergence occurs on the return to the discrete system, the adjustment depends on which criterion prompted the return.

$$\begin{aligned} &\text{If } \varepsilon > \varepsilon_q, \text{ then } \varepsilon_q \to f\,\varepsilon_q \\ &\overline{A}_i > \delta_U, \text{ then } \delta_U \to 1 + f\,(\delta_U - 1) \\ &\overline{A}_i < \delta_L, \text{ then } \delta_L \to 1/[1 + f\,(1/\delta_L - 1)] \\ &\Delta P \text{ reached, then } \Delta P \to f\,\Delta P \end{aligned} \tag{5}$$

If divergence occurs on return to the discrete system, f is set to 0.5 and all four return keys are accordingly adjusted.

Initial efforts established that efficient analysis would be achieved in a variety of cases with the choice:

$$\varepsilon_q = 0.2,\ \delta_U = 4,\ \delta_L = 0.3,\ \text{and}\ \kappa = 0.08 \tag{6}$$

This strategy should be considered as a first cut only. Additional improvements are certainly possible. For example, a good initial value of ε_q can probably be surmised from the relation between error norm and convergence rate in the first series of solutions in STAGSC-1. Also it may be better to adjust all the strategy parameters on any return to the discrete system. While a more efficient AUTORITZ may be forthcoming, the present version was evaluated through comparison to solution with STAGSC-1. AUTORITZ and STAGSC-1 were both applied in a study of five structural configurations with significant nonlinearity. The strategy in AUTORITZ was in all cases based on the default values for the parameters (Reference 6). The results indicate that in comparison to use of STAGSC-1 with quadratic extrapolation for initial estimates, use of AUTORITZ leads to a saving in computer time by a factor of three to five.

SECTION 4

Input to RRSTAGS

In the discussion of input data for Program RRSTAGS an example case is included for demonstration. An imperfect cylindrical panel subjected to axial compression in the form of uniform end-shortening. The properties of the panel are shown in Figure 5. All the four edges are simply supported. The panel is free from initial stresses but deviates from the true geometric shape. The initial imperfection is represented by a lateral displacement (in meters) of the form

$$\begin{aligned} W_0 = {} & 0.05 \sin \frac{x\pi}{L} \sin (12\ y) + 0.02 \sin \frac{x\pi}{L} \sin (24\ y) \\ & + 0.02 \sin \frac{2x\pi}{L} \sin (12\ y) + 0.02 \sin \frac{3x\pi}{L} \sin (24\ y) \\ & + 0.02 \sin \frac{2x\pi}{L} \sin (12\ y) + 0.01 \sin \frac{3x\pi}{L} \sin (12\ y) \\ & + 0.02 \sin \frac{3x\pi}{L} \sin (36\ y) \end{aligned} \tag{8}$$

A maximum of six Ritz functions will be used in RRSTAGS analysis. For initiation of the analysis four functions (one linear and three nonlinear) are obtained through solution of STAGSC-1 with a 19 x 19 uniform finite element grid. The analysis is carried to a uniform end shortening of 0.459 in. (about three times the bifurcation buckling load). The corresponding STAGSC-1 input data are:

```
IMPERFECT PANEL
3, 0, 1
1
1, 0, 1
.1, .1, 3.0
0, 1800, 3, 20
19, 19
1
1. +6, .3, 0, .1
1, 1, 1
1, .5
5
0., 51., 0., 30., 100.
1, 7
25.5, 15., 51., 30., .05
25.5, 7.5, 51., 15., .02
12.75, 15., 25.5, 30., .02
12.75, 7.5, 25.5, 15., .01
8.5, 15., 17., 30., .01
8.5, 7.5, 17., 15., .002
8.5, 3.75, 17., 7.5, .002
411
0, 0, 0, 0
110, 011
110, 101
010, 011
110, 101
1
1, 2
.153, -1, 1, 1
0., -1, 2, 1, 10
4, 0, 0, 0, 0, 2
```

The input to RRSTAGS is divided in groups, generally with similar type of information within one group. Not all groups need be included in a given run. The presence of data in a group is indicated by a label. After the label follows the input data for the indicated group. The input data in any given group is terminated by a card with an X in column 1. The groups can be read in any order. If an input group that is needed for conclusions of the analysis is omitted the program will use default values for certain parameters. In a restart it will use data from the previous run.

Initial conditions used by RRSTAGS are usually those defined in a previous STAGS run. It is, however, also possible to define initial displacements and velocities modewise. See input item "INIT".

Presently, two different criteria are used for deciding when to go back to the big system for updating the mode set. The first tests on the error of the first variation in the big system (admissible error EPSQ), the second tests on how much the diagonal terms change in the second variation of the reduced equation system. It is also possible to force the return to the big system after a given number of steps.

In the following the input groups are discussed separately. The label is first given, followed by an indication of the type of input included in the group. After that the notations for the different parameters are given and their meaning explained. Example input is then given pertaining to the collapse of an imperfect panel of composite material by use of the AUTORITZ procedure.

TEXT
Any alphanumeric information identifying the problem

EXAMPLE:
```
TEXT
  IMPERFECT PANEL
X
```

PARAMS
General parameters controlling the analysis

MAXNS, KMETH, LIN, KSAVE, KT25, KEXTR, KCHCK

MAXNS Maximum number of modes ever to be used in this analysis

KMETH Integration Method
- 1 = Trapezoidal Rule
- 2 = Gear 2nd order
- 3 = Gear 3rd order
- 4 = Park Method

LIN
- = 0 nonlinear analysis
- = 1 nonlinear terms neglected

KSAVE Number of solutions saved at the end of run for restart. Note - KSAVE.LE.4 !

KT25
- = 1 Subspace solutions are saved in the data base
- = 0 Subspace solutions not saved

KEXTR
- = 0 Extrapolation inactive
- = 1 Quadratic extrapolation is used

KCHCK Equilibrium checked every KCHCK-th load step (default = 10)

Comments: Saving subspace solutions, i.e., the vector of Ritz function amplitudes makes it possible to restart at any load level.

Use of quadratic extrapolation usually leads to faster convergence. In exceptional cases it may lead to displacements corresponding to a negative determinant. In such a case solutions may possibly be obtained after the extrapolation is suppressed.

KCHCK governs the return to the discrete system for check of accuracy. Each return corresponds to computation of the first variation. The computer time spent on this computation generally is much greater than time spent on integration of the reduced system.

Example:

```
PARAMS
6, 4, 0, 2, 0, 1, 5
X
```

STRAT
Parameters relating to the computational strategy

NEWT, NCUT, NITMAX, EPS, EPSQ

NEWT	Number of refactorings allowed
NCUT	Total number of step cuts allowed (recommended 1)
NITMAX	Max number of iterations allowed (recommended 15)
EPS	Maximum displacement error allowed in equilibrium iteration (recommended 10^{-5})
EPSQ	Error in equilibrium where mode set will be changed (recommended 0.2)

Comments: There is usually no reason to restrict the number of factorings. Use a large number for NEWT. If NEWT and NCUT both are negative (NEWT otherwise meaningless), the true Newton method is used for solution of the reduced system. Since the system is small this appears usually to be somewhat more efficient. Also the risk of unwanted nonconvergence is diminished. NCUT, NEWT = -1, -1 or -1, -2 appears to be good choices for most cases.

EXAMPLE:

```
STRAT
-1, -2, 10, .00001, .2
X
```

STATIC
Load factors for a static analysis.

PAST, DPA, PAMAX, PBST, DPB, PBMAX

PAST	Starting load factor PA
DPA	Starting load increment
PAMAX	Final load factor
PBST	Starting load factor PB
DPB	Starting load increment
PBMAX	Max load factor for System B

Comments: The load steps are automatically controlled based on the rate of convergence. Starting load factor and initial step may be chosen about a quarter of the step in a STAGSC-1 analysis, say 0.05 times estimated collapse load.

EXAMPLE:

```
STATIC
0.05, 0.05, 3.0, 0., 0., .
X
```

DYNAM
Load and time control parameters for time integration problems.

LTYPE, TO, DT, TMAX, OMA, OMB, PAMAX, PBMAX

LTYPE	Type of dynamic loading
TO	Starting time for dynamic analysis
DT	Starting time increment
TMAX	Time where analysis stops
OMA	Coefficient in dynamic loading equation for System A
OMB	Coefficient in dynamic loading equation for System B
PAMAX	Max dynamic load factor for System A
PBMAX	Max dynamic load factor for System B

Comments: The load distribution is determined by STAGSC-1 input. The dynamic capability of RRSYS is somewhat limited. There is no automatic error control.

The type of loading governed by LTYPE must be the same for the A-and B-Systems.

If LTYPE = 1

```
PA = sin (OMA * T) * PAMAX
PB = sin (OMB * T) * PBMAX
```

```
LTYPE = 2

PA = PAMAX
PB = PBMAX
```

```
LTYPE = 3

PA = MIN (OMA * T, PAMAX)
PB = MIN (OMB * T, PBMAX
```

The group DYNAMIC is not included in the example case. [For a case in which the load factor of the A and B System both increase linearly during 0.001 second up to 1.0 and then are held constant we could have

```
DYNAMIC
2, 0, 0.0001, 0.005, 1000., 1000., 1., 1.
X                                        ]
```

CONVERG
Convergence parameter

CFAC

CFAC exponent in formula for adjustment of return keys. The function f (Eq. 5 in Section 3) is defined by

$$f = 10^{-CFAC\ (N-5)}$$

where N is the number of iterations at previous return to STAGSC-1. (Recommended CFAK - 0.08)

Example:

```
CONVERG
0.08
X
```

RESTART
Allows the user to specify vectors to be used as initial conditions on a restart.

LABEL-VEL, LABEL-DIS

LABEL-VEL
LABEL-DIS
Labels of vectors in data base to be used as initial velocity and displacement vectors in a restart. To restart an RRSTAGS run from the beginning use the vector

"NULL" for both LABEL-VEL and LABEL-DIS. This is a zero-length vector (all elements = 0) with the correct number of freedoms, which is always in the system.

SELMODES
Allows the user to select the mode vectors used in an RRSYS analysis.

LABEL1
LABEL2
etc.

LABELi, Name of vector in data base to be included as a Ritz-function.

Comments: Vectors computed by use of STAGSC-1 are named DIS-A...A, DIS-A...B, etc. in each separate run. If an additional STAGSC-1 is performed using the same data base, they will be named DIS-B...A, DIS-B...B, etc. User defined vectors (defined in ECHO, DBS, or in RRSTAGS) are named UMODE...A, UMODE...B, etc. in the order they are created. If the label SELMODES is included the input defines the labels of the vectors to be included. If SELMODES is not present in an AUTORITZ run all vectors are included unless the number of vectors in the data base exceeds the maximum (defined under PARAMS). If the SELMODES group is not included and the number of modes in the data base exceeds MAXNS, the program automatically selects the vectors that contribute most to the solution vector.

Example: SELMODES input is not needed in the example case.

[If five vectors have been created in a nonlinear STAGSC-1 run but the analyst wants to exclude the linear solution in a subsequent AUTORITZ run the input would be as follows

```
SELMODES
DIS-A...B
DIS-A...C
DIS-A...D
DIS-A...E
X        ]
```

USERMODES
Allows the user to define the shape of the mode vectors by using functions.

IUNIT, MODE, COMPONENT, X1, Y1, XL, YL, WAMP

IUNIT Index of shell unit

MODE Index of Mode (to be generated)

COMPONENT Displacement component defined

COMPONENT = 1	Displacement	U
2	-u-	V
3	-v-	W

X1, Y1 Value of shell coordinates at one maximum

XL Half-wave length of the mode in the X-direction (XL = ∞ ,read 0.)

YL Half-wave length of the mode in the Y-direction (YL = ∞ ,read 0.)

WAMP Amplitude of imperfection component.

Comments: One function can contain more than one displacement component.

Example: USERMODES need not be included in the example

[In a rather approximate postbuckling analysis of a 10 x 10 in flat plate under shear we may use the function

$$V = X \sin(X_\pi/1000.)$$

representing the applied shear strain and

$$W = X_2 \sin\frac{X_\pi}{10} \sin\frac{Y_\pi}{10} + X_3 \sin\frac{2x_\pi}{10} \sin\frac{2y_\pi}{10}$$

The input then would be

```
USERMODES

1   1   2   5000.     0.     1000.   0.   1.
1   2   3      5.     5.       10.  10.   1.
1   3   3      2.5    2.5       5.   5.   1.
X]
```

DAMP
Defines damping properties in the reduced system.

CMASS, CSTFF

CMASS Coefficient of mass matrix in calculating the damping matrix

CSTFF Coefficients of the stiffness matrix in ditto

Comments: The damping is assumed to have the form

(DAMPING MATRIX) = CMASS*(MASS MATRIX) +
CSTFF*(STIFFNESS MATRIX)

Example:

The input group DAMP is not needed in this case.

[In a dynamic case with the damping matrix equal to 10^{-6} times the stiffness matrix the input would be

```
DAMP
0.,000001
X]
```

TEST
Controls diagnostic output.

KTEST, LBUFR, NRET

KTEST = 0 No diagnostic information (recommended
= 1 Certain diagnostic information
= 2 Lots of diagnostic information

LBUFR = Length of VM buffer (default = 1000 words)

NRET Number of load or time steps after which RR-analysis shall be terminated. The job then continues with a STAGS2 restart.

Comments: NRET determines a maximum step size, i.e., load increment between returns to the discrete system. (Recommended 50 to 100.)

Example:

```
TEST
0, 0, 60
X
```

OUTPUT
Defines frequency and volume of regular output

KPR, KTIME, KVEL, KITD

KPR Output every KPR-th load or time step

KTIME = 1

KVEL = 0 Velocity vector not printed
= 1 Velocities are printed

KITD = 0 No iteration data
= 1 Intermediate iteration data (Recommended = 1)
= 2 In addition, reduced stiffness and stability matrices are printed whenever they are computed

Comments: It seems reasonable that a relatively new user of the system uses KITD = 1. After experience the choice is less clear KTIME is presently not operational.

Example:

```
OUTPUT
20, 1, 0, 1
X
```

SELOUT
Allows the user to print selected output

NODE, IUNIT, IROW, ICOL

NODE Number of node for which output shall be given

IUNIT Branch number

IROW Row number

ICOL Column number

Comments: In the element unit (STAGSC-1) the unit is referred to by its number (in the first entry), punch zero for IUNIT, IROW, ICOL. For nodes in the shell unit NODE is set equal to zero.

Example:

```
SELOUT
0, 1, 3, 3
0, 1, 3, 5
X
```

RETURNS

Defines a number of load levels at which a return to the discrete system is made. These loads need not be evenly spaced.

NRLOAD, ((RLOAD (J)), J = 1, NRLOAD)

NRLOAD Number of load steps where forced returns occur

RLOAD Corresponding load factors PA

Comments: This input data can be used in lieu of NRET, in that case a very high number is read for NRET. RLOAD can be used to force a return to the discrete system at the maximum load factor.

Example:

```
RETURNS
1, 3.0
X
```

DIAG
Defines changes in the diagonal terms of the factored matrix of the reduced system.

KCHDG, CHDOWN, CHUP

KCHDG Diagonal terms of reduced 2nd variation checked every KCHDG-th load or time step (Recommended 4)

CHDOWN Max allowable relative decrease of any diagonal term

CHUP Max allowable relative increase of any diagonal term

Comments: The use of these input data is discussed in Section 2.3. Experience indicates that the starting values CHDOWN = 0.3 and CHUP = 3.0 are reasonable. The values are automatically adjusted in AUTORITZ.

Example:

```
DIAG
4, 0.3, 3.0
X
```

EXECUTE
Initiates execution.

Example

```
EXECUTE
X
```

SECTION 5

INPUT TO PROGRAM DBS

It is possible to perform a large number of functions in DBS, such as vector and matrix operations. These are most conveniently carried out in the interactive mode. Complete instructions for such operations will be included in a 1982 NASA Report (Reference 7). Here we include only batch processing that may be required in connection with a POIS analysis.

These are audit of files in Data Base Delete file from Data Base, Display data on file or parts of file, Insert or change data in Data Base file.

The following operations are given as examples for demonstration.

Some command sequences and associated data input:

Card input	Function
DATA	First card in any DBS input data deck
STATUS	Prints information regarding the status of a Rayleigh-Ritz analysis
FILES	Prints list of files presently in the data base
DELETE (LFN) X	Deletes data set (vector) from the data base File Name (alphanumeric)
USERMODES (IUNIT), (MODE), (COMPONENT), (PARAMETERS)	Defines user selected mode vectors
X	Defines mode shape for each unit, mode number and displacement component The parameters are defined under USERMODES in Section 4
SELMODES (LFN1) (LFN2) . . (LFNN) X	Selects modes to be used in Rayleigh-Ritz analysis Names under which mode vectors are stored in the data base
EDIT, LFN	Activates line editor, loads data base
@L	LFN containing card images
@P,n	List the whole file
@I,n,i (cards)	Print line number n Insert cards beginning with line n and number these with increment i
@D,n,i (card (card) (card) (card) X	Delete line n and insert the following cards, number these with increment i Terminate line editing.
EXECUTE	Last card in any DBS input data check.

Example:

1. Audit the data base file

2. Delete a file named DIS-A...F from the data base

3. Display data on file named I1.

4. Change line 1100 on I1 to
   1, 8

   Insert between lines 1400 and 1500 on I1
   4.25 3.75 8.5 8.5 0.001

5. List modified file

These operations are all performed by use of the input deck:

```
DATA
FILES
DELETE
DIS-A...F
X
EDIT, I1

@L
@D, 1100
  1,8
@I, 1450
 4.25   3.75   8.5   7.5   .001
@L
X
EXECUTE
```

SECTION 6

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